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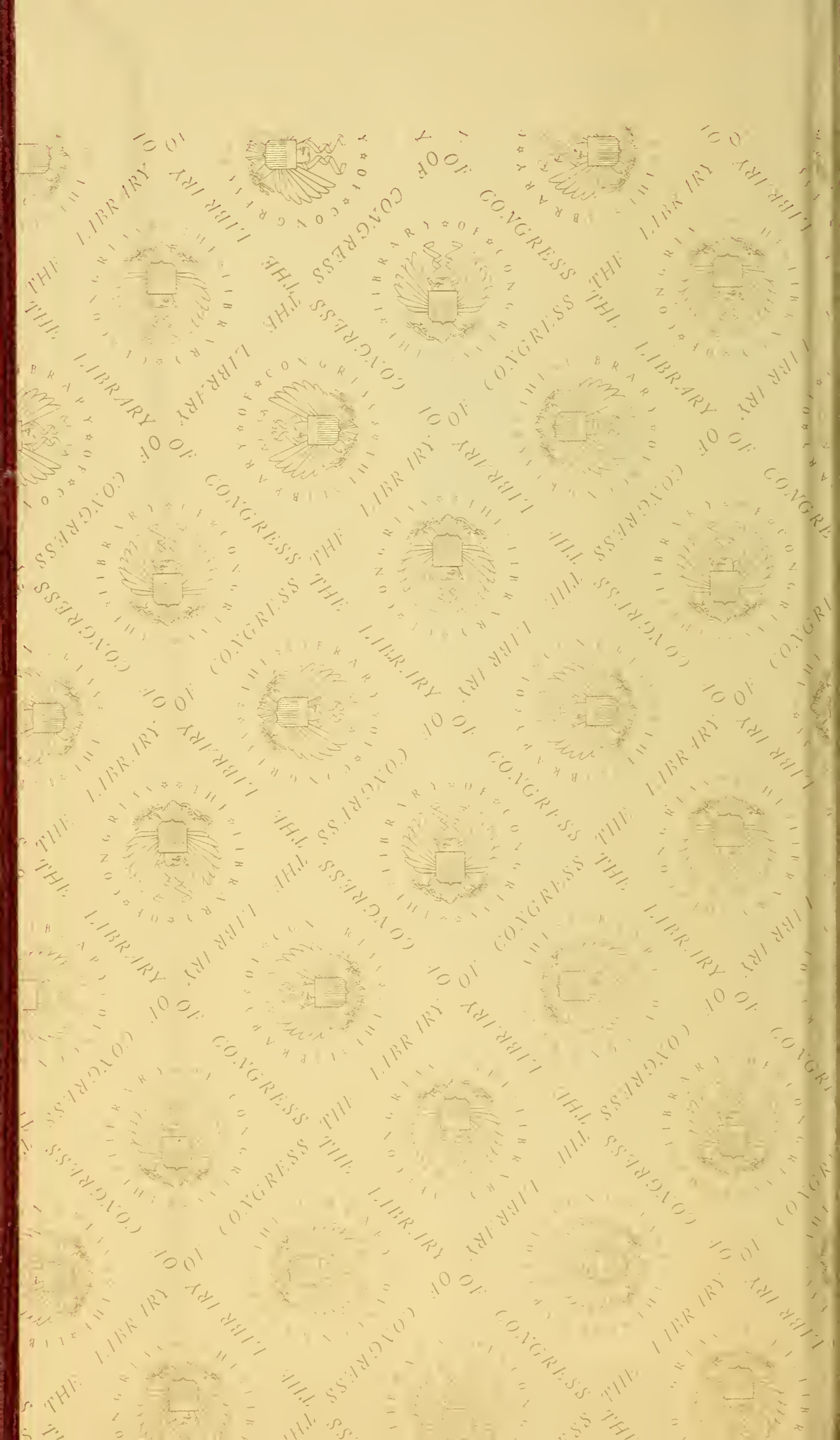
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Telescopic View of the Moon.

Telescopic View of the Moon when five days old.

A

COMPENDIUM OF ASTRONOMY;

CONTAINING THE

ELEMENTS OF THE SCIENCE,

FAMILIARLY EXPLAINED AND ILLUSTRATED,

WITH THE LATEST DISCOVERIES.

ADAPTED TO THE USE OF

SCHOOLS AND ACADEMIES,

AND OF THE

GENERAL READER.

STEREOTYPE EDITION.

BY DENISON OLMSTED, A. M.

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PREFACE.

This small volume is intended to afford to the General Reader, and to the more advanced pupils of our Schools and Academies, a comprehensive outline of Astronomy with its latest discoveries. For its perusal, no further acquaintance with mathematics is necessary, than a knowledge of common arithmetic; although some slight knowledge, at least, of geometry and trigonometry will prove very useful.

By omitting mathematical formulæ, and employing much familiar illustration, we have endeavored to bring the leading facts and doctrines of this noble and interesting science, within the comprehension of every attentive and intelligent reader. In no science, more than in this, are greater advantages to be derived from a lucid arrangement—an order which brings out every fact and doctrine of the science, just in the place where the mind is ready to receive it. A certain maturity of mind, and power of reflection, are, however, indispensable for understanding this science. Astronomy is no study for children. Let them be employed on subjects more suited to the state of their capacities, until those faculties are more fully developed, which will enable them to learn to conceive correctly of the celestial motions. A work on Astronomy that is *very easy*, must be very superficial, and will be found to enter little into the arcana of the science. The riches of this mine lie deep; and no one can acquire them, who is either incompetent or unwilling to penetrate beneath the surface.

Although this treatise is based on the larger work of the author, ("Introduction to Astronomy,") prepared for the students of Yale College, yet it is not merely an abridgment of that. It contains much original matter adapted to the peculiar exigencies of the class of readers for whom it is intended. The few passages taken verbatim from astronomical writers,

are not, as in the larger work, always accredited to their respective authors, as this was deemed unimportant in a work of this description.

It is strongly recommended to all who study this science, even in its most elementary form, early to commence learning the names of the constellations, and of the largest of the individual stars, in the order in which they are described in the last part of the work. A celestial globe will be found a most useful auxiliary in this as in every other part of Astronomy. If it cannot supersede, it may greatly aid reflection. The reader also should, if in his power, take frequent opportunities of viewing the heavenly bodies through the telescope. This will add much to his intelligence, and increase his interest in the study.

ADVERTISEMENT.

Since the stereotype edition of this work was first published, several new and interesting discoveries have been added to Astronomy, an account of which will be found in the *Supplement*. They make no change in the great facts and doctrines of the science, but these remain unaltered and immutable; while the new discoveries extend still further our knowledge of the Universe. We have, therefore, no occasion to alter the text, except perhaps very slightly in one or two statements, but by giving whatever is new and important in the form of a supplement, (to which we may add as every successive discovery is made,) we shall endeavor to secure to this treatise the freshness and accuracy of the most recent compilations, as well as furnish to the schools what has been thoroughly tested and approved by the most able teachers of the Union.

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COMPENDIUM OF ASTRONOMY.

PRELIMINARY OBSERVATIONS.

1. ASTRONOMY *is that science which treats of the heavenly bodies.*

More particularly, its object is to teach what is known respecting the Sun, Moon, Planets, Comets, and Fixed Stars; and also to explain the methods by which this knowledge is acquired.

Astronomy is sometimes divided into Descriptive, Physical, and Practical. Descriptive Astronomy respects *facts;* Physical Astronomy, *causes;* Practical Astronomy, the *means of investigating the facts,* whether by instruments, or by calculation. It is the province of Descriptive Astronomy to observe, classify, and record, all the phenomena of the heavenly bodies, whether pertaining to those bodies individually, or resulting from their motions and mutual relations. It is the part of Physical Astronomy to explain the causes of these phenomena by investigating and applying the general laws on which they depend; especially by tracing out all the consequences of the law of universal gravitation. Practical Astronomy lends its aid to both the other departments.

2. Astronomy is the most ancient of all the sciences. At a period of very high antiquity, it was cultivated in Egypt, in Chaldea, and in India. Such knowledge of the heavenly bodies as could be acquired by close and long continued observation, without the aid of instru-

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1. Define Astronomy. What does it teach? Name the three parts into which it is divided. What does *Descriptive* Astronomy respect? What does *Physical* Astronomy? What does *Practical* Astronomy? What is the peculiar province of each?

ments, was diligently amassed; and tables of the celestial motions were constructed, which could be used in predicting eclipses, and other astronomical phenomena.

About 500 years before the Christain era, *Pythagoras*, of Greece, taught astronomy at the celebrated school at Crotona, (a Greek town on the southeastern coast of Italy,) and exhibited more correct views of the nature of the celestial motions, than were entertained by any other astronomer of the ancient world. His views, however, were not generally adopted, but lay neglected for nearly 2000 years, when they were revived and established by Copernicus and Galileo. The most celebrated astronomical school of antiquity, was at Alexandria in Egypt, which was established and sustained by the Ptolemies, (Egyptian princes,) 300 years before the Christian era. The employment of instruments for measuring angles, and bringing in trigonometrical calculations to aid the naked powers of observation, gave to the Alexandrian astronomers great advantages over all their predecessors.

The most able astronomer of the Alexandrian school was *Hipparchus*, who was distinguished above all the ancients for the accuracy of his astronomical measurements and determinations. The knowledge of astronomy possessed by the *Alexandrian* school, and recorded in the *Almagest*, or great work of *Ptolemy*, constituted the chief of what was known of our science during the middle ages, until the fifteenth and sixteenth centuries, when the labors of *Copernicus* of Prussia, *Tycho Brahe*

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2. Trace the *history* of Astronomy. Among what ancient nations was it cultivated? What kind of knowledge of the heavenly bodies was amassed? Who was *Pythagoras?* When and where did he live? Where was his school? How correct were his views? Were they generally adopted? Give an account of the Alexandrian school. When was it established and by whom? What gave it great advantages over all its predecessors? Give some account of Hipparchus—of Ptolemy—of Copernicus—of Tycho Brahe—of Kepler—of Galileo—of Newton—of La Place. Specify the respective labors of each.

of Denmark, *Kepler* of Germany, and *Galileo* of Italy, laid the solid foundations of modern astronomy. Copernicus expounded the true system of the world, or the arrangement and motions of the heavenly bodies; Tycho Brahe carried the use of instruments, and the art of astronomical observation, to a far higher degree of accuracy than had ever been done before; Kepler discovered the great laws which regulate the movements of the planets; and Galileo, having first enjoyed the aid of the telescope, made innumerable discoveries in the solar system. Near the beginning of the eighteenth century, *Sir Isaac Newton* discovered, in the law of universal gravitation, the great principle that explains the causes of all celestial phenomena; and recently, *La Place* has more fully completed what Newton begun, having followed out all the consequences of the law of universal gravitation, in his great work, the Mecanique Celeste.

3. Among the ancients, astronomy was studied chiefly as subsidiary to astrology. *Astrology was the art of divining future events by the stars.* It was of two kinds, natural and judicial. *Natural Astrology*, aimed at predicting remarkable occurrences in the natural world, as eathquakes, volcanoes, tempests, and pestilential diseases. *Judicial Astrology*, aimed at foretelling the fates of individuals, or of empires.

4. Astronomers of every age, have been distinguished for their persevering industry, and their great love of accuracy. They have uniformly aspired to an exactness in their inquiries, far beyond what is aimed at in most geographical investigations, satisfied with nothing short of numerical accuracy wherever this is attainable; and years of toilsome observation, or laborious calculation, have been spent with the hope of attaining a few se-

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3. Define Astrology. What was Natural and what Judicial Astrology?

4. What is said of the industry and accuracy of astronomers? Can this science be taught by artificial aids alone?

conds nearer to the truth. Moreover, a severe but delightful labor is imposed on all, who would arrive at a clear and satisfactory knowledge of the subject of astronomy. Diagrams, artificial globes, orreries, and familiar comparisons and illustrations, proposed by the author or the instructor, may afford essential aid to the learner, but nothing can convey to him a perfect comprehension of the celestial motions, without much diligent study and reflection.

5. In this treatise, we shall for the present assume the *Copernican system* as the true system of the world, postponing the discussion of the evidence on which it rests to a late period, when the learner has been made extensively acquainted with astronomical facts. This system maintains (1,) That the *apparent* diurnal revolution of the heavenly bodies, from east to west, is owing to the *real* revolution of the earth on its own axis from west to east, in the same time; and (2,) That the sun is the center around which the earth and planets all revolve from west to east, contrary to the opinion that the earth is the center of motion of the sun and planets.

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5. What system is assumed as the true system of the world? Specify the two leading points in the Copernican system.

PART I.—OF THE EARTH.

CHAPTER I.

OF THE FIGURE AND DIMENSIONS OF THE EARTH, AND THE DOCTRINE OF THE SPHERE.

6. *The figure of the earth is nearly globular.* This fact is known, first, by the circular form of its shadow cast upon the moon in a lunar eclipse; secondly, from analogy, each of the other planets being seen to be spherical; thirdly, by our seeing the tops of distant objects while the other parts are invisible, as the topmast of a ship, while either leaving or approaching the shore, or the lantern of a light-house, which when first descried at a distance at sea, appears to glimmer upon the very surface of the water; fourthly, by the testimony of navigators who have sailed around it; and, finally, by actual observations and measurements, made for the express purpose of ascertaining the figure of the earth, by means of which astronomers are enabled to compute the distances from the center of the earth of various places on its surface, which distances are found to be nearly equal.

The effect of the rotundity of the earth upon the appearance of a ship, when either leaving or approaching the spectator, is illustrated by Fig. 1.

As light proceeds in straight lines, it is evident that, if the earth is round, the top of the ship ought to come into view before the lower parts, when the ship is approaching the spectator at A, and to remain longest in view when the ship is leaving him. But, were the earth

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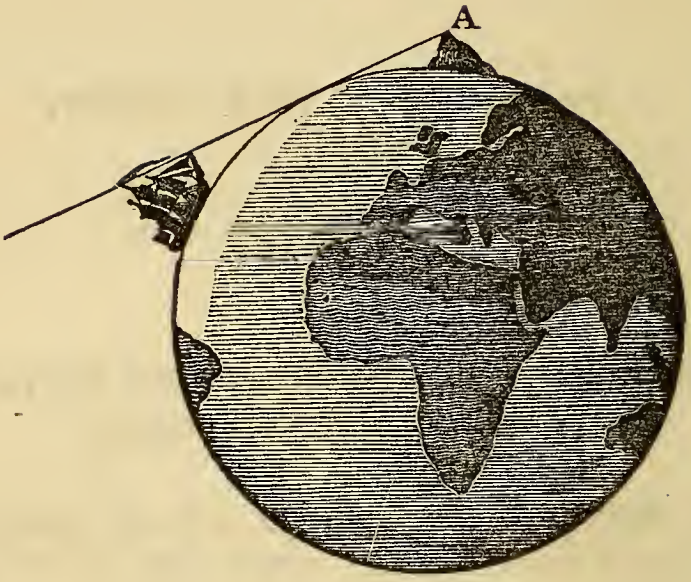
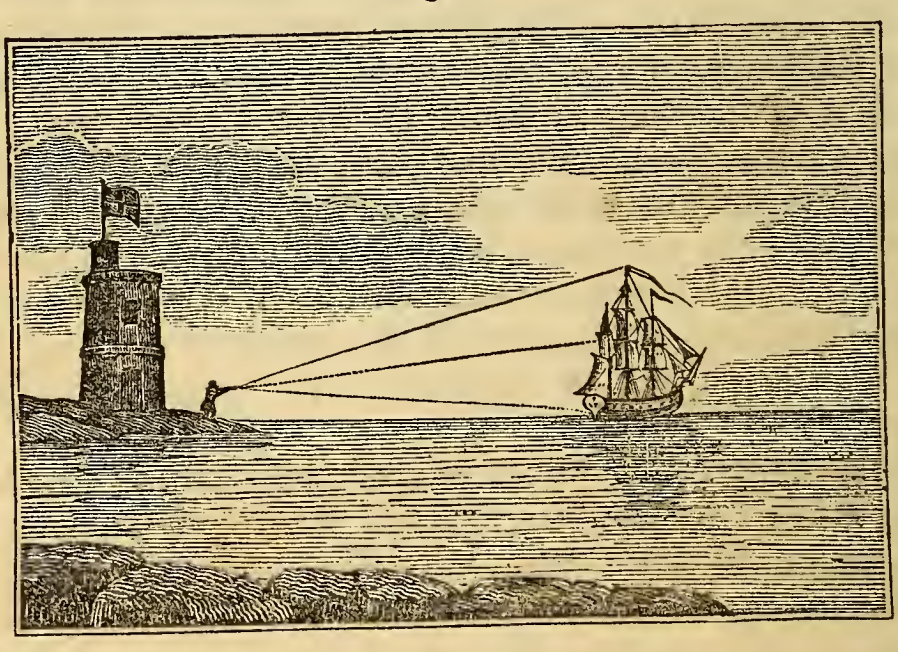
6. What is the figure of the earth? Enumerate the various proofs of its rotundity.

Fig. 1.



a continued plane, then the spectator would see all parts of the ship at the same time, as is represented in the annexed figure.

Fig. 2.



7. The foregoing considerations show that the form of the earth is spherical; but more exact determinations prove, that the earth, though nearly globular, is not exactly so; its diameter from the north to the south pole is about 26 miles less than through the equator, giving to the earth the form of an oblate spheroid, or a flattened sphere resembling an orange. We shall reserve the ex-

planations of the methods by which this fact is established, until the learner is better prepared than at present to understand them.

The mean or average *diameter of the earth*, is 7912.4 miles, a measure which the learner should fix in his memory as a standard of comparison in astronomy, and of which he should endeavor to form the most adequate conception in his power. The circumference of the earth is about 25,000 miles. Although the surface of the earth is uneven, sometimes rising in high mountains, and sometimes descending in deep valleys, yet these elevations and depressions are so small in comparison with the immense volume of the globe, as hardly to occasion any sensible deviation from a surface uniformly curvilinear. The irregularities of the earth's surface, in this view, are no greater than the rough points on the rind of an orange, which do not perceptibly interrupt its continuity; for the highest mountain on the globe is only about five miles above the general level; and the deepest mine hitherto opened is only about half a mile.*

Now $\frac{5}{7912} = \frac{1}{1582}$, or about one sixteen hundredth part of the whole diameter, an inequality which, in an artificial globe of eighteen inches diameter, amounts to only the eighty eighth part of an inch.

8. The greatest difficulty in the way of acquiring correct views in astronomy, arises from the erroneous notions that pre-occupy the mind. To divest himself

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7. What is the *exact* figure of the earth? How much greater is its diameter through the equator than through the poles? What is the mean average diameter of the earth? What is its circumference? Do the inequalities on the earth's surface affect its rotundity? To what may these be compared? How high is the highest mountain above the general level? How deep is the deepest mine? To how much would this amount on an artificial globe eighteen inches in diameter?

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* Sir John Herschel.

of these, the learner should conceive of the earth as a huge globe occupying a small portion of space, and encircled on all sides with the starry sphere. He should free his mind from its habitual proneness to consider one part of space as naturally *up* and another *down*, and view himself as subject to a force which binds him to the earth as truly as though he were fastened to it by some invisible cords or wires, as the needle attaches itself to all sides of a spherical loadstone. He should

Fig. 3.

dwell on this point until it appears to him as truly *up* in the direction of BB, CC, DD, (Fig. 3,) when he is at B, C, and D, respectively, as in the direction AA, when he is at A.

DOCTRINE OF THE SPHERE.

9. The definitions of the different lines, points, and circles, which are used in astronomy, and the propositions founded upon them, compose the *Doctrine of the Sphere.*

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8. Whence arises the greatest difficulty in acquiring correct views in astronomy? How should the learner conceive of the earth? Illustrate by figure 3.

9. Doctrine of the sphere—define it.

10. A section of a sphere by a plane cutting it in any manner, is a circle. *Great circles* are those which pass through the center of the sphere, and divide it into two equal hemispheres: *Small circles*, are such as do not pass through the center, but divide the sphere into two unequal parts. Every circle, whether great or small, is divided into 360 equal parts called *degrees*. A degree, therefore, is not any fixed or definite quantity, but only a certain aliquot part of any circle.*

The *axis* of a circle, is a straight line passing through its center at right angles to its plane.

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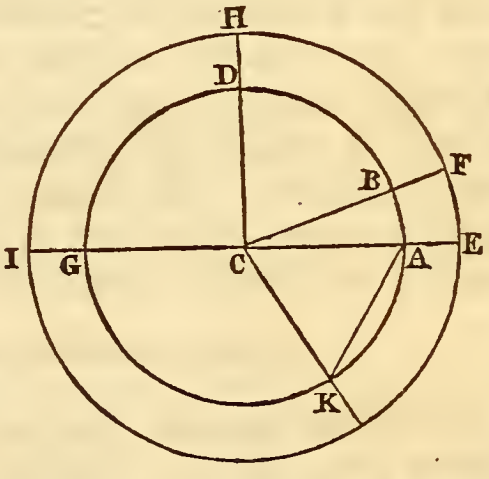
* As this work may be read by some who are unacquainted with even the rudiments of geometry, we annex a few particulars respecting angular measurements.

A line drawn from the center to the circumference of a circle is called a *radius*, as CD, fig. 4.

Any part of the circumference of a circle is called an *arc*, as AB, or BD.

An angle is measured by the arc included between two radii. Thus, in the annexed figure, the angle contained between the two radii CA and CB, that is, the angle ACB, is measured by the arc AB. But this arc is the same part of the smaller circle that EF is of the greater. The arc AB therefore contains the same number of degrees as the arc EF, and either may be taken for the measure of the angle ACB. As the whole circle contains 360°, it is evident that the quarter of a circle, or *quadrant* ABD, contains 90°, and the semicircle ABDG contains 180°.

Fig. 4.



The *complement* of an arc or angle, is what it wants of 90°. Thus BD is the complement of AB, and AB is the complement of BD. If AB denotes a certain number of degrees of latitude, BD will be the complement of the latitude or the *co-latitude*, as it is commonly written.

The *supplement* of an arc or angle, is what it wants of 180°. Thus BA is the supplement of GDB, and GDB, is the supplement of BA. If BA were 20° of longitude, GDB its supplement would be 160°.

An angle is said to be *subtended* by the side which is opposite to it. Thus in the triangle ACK, the angle at C is subtended by the side AK, the angle at A by CK, and the angle at K by CA. In like manner a side is said to be subtended by an angle, as AK by the angle at C.

The *pole* of a great circle, is the point on the sphere where its axis cuts through the sphere. Every great circle has two poles, each of which is every where 90° from the great circle.

All great circles of the sphere cut each other in two points diametrically opposite, and consequently, their points of section are 180° apart.

A great circle which passes through the pole of another great circle, cuts the latter at right angles.

The great circle which passes through the pole of another great circle and is at right angles to it, is called a *secondary* to that circle.

The angle made by two great circles on the surface of the sphere, is measured by the arc of another great circle, of which the angular point is the pole, being the arc of that great circle intercepted between those two circles.

11. In order to fix the position of any plane, either on the surface of the earth or in the heavens, both the earth and the heavens are conceived to be divided into separate portions by circles, which are imagined to cut through them in various ways. The earth thus intersected is called the *terrestrial*, and the heavens the *celestial* sphere. The learner will remark, that these circles have no existence in nature, but are mere landmarks, artificially contrived for convenience of refer-

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10. What figure is produced by the section of a sphere? Define *great* circles. Define *small* circles. Into how many degrees is every circle divided? Is a degree any fixed or definite quantity? What is the *axis* of a circle? What is the *pole* of a circle? How do all great circles cut each other? How is a great circle cut by another great circle passing through its pole? What is the *secondary* of a circle? How is the angle made by two great circles on the surface of the sphere measured?

11. How are the earth and the heavens conceived to be divided? What constitutes the terrestrial sphere? What the celestial? Have these circles any existence in nature? In what do the heavenly bodies appear to be fixed?

ence. On account of the immense distance of the heavenly bodies, they appear to us, wherever we are placed, to be fixed in the same concave surface, or celestial vault. The great circles of the globe, extended every way to meet the concave surface of the heavens, become circles of the celestial sphere.

12. The *Horizon* is the great circle which divides the earth into upper and lower hemispheres, and separates the visible heavens from the invisible. This is the *rational* horizon. The *sensible* horizon, is a circle touching the earth at the place of the spectator, and is bounded by the line in which the earth and skies seem to meet. The sensible horizon is parallel to the rational, but is distant from it by the semi-diameter of the earth, or nearly 4,000 miles. Still, so vast is the distance of the starry sphere, that both these planes appear to cut that sphere in the same line; so that we see the same hemisphere of stars that we should see if the upper half of the earth were removed, and we stood on the rational horizon.

13. The poles of the horizon are the zenith and nadir. The *Zenith* is the point directly over our head, and the *Nadir* that directly under our feet. The plumb line is in the axis of the horizon, and consequently directed towards its poles.

Every place on the surface of the earth has its own horizon; and the traveller has a new horizon at every step, always extending 90 degrees from him in all directions.

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12. Define the *horizon*. Distinguish between the rational and the sensible horizon. What is the distance between the sensible and rational horizons? How do both appear to cut the starry heavens?

13. What are the poles of the horizon? Define the *zenith*. Define the *nadir*. How is the plumb line situated with respect to the horizon? How many horizons are there on the earth?

14. *Vertical circles* are those which pass through the poles of the horizon, perpendicular to it.

The *Meridian* is that vertical circle which passes through the north and south points.

The *Prime Vertical*, is that vertical circle which passes through the east and west points.

The *Altitude* of a body, is its elevation above the horizon, measured on a vertical circle.

The *Azimuth* of a body, is its distance measured on the horizon from the meridian to a vertical circle passing through the body.

The *Amplitude* of a body, is its distance on the horizon, from the prime vertical, to a vertical circle passing through the body.

Azimuth is reckoned 90° from either the north or south point; and amplitude 90° from either the east or west point. Azimuth and amplitude are mutually complements of each other. When a point is *on* the horizon, it is only necessary to count the number of degrees of the horizon between that point and the meridian, in order to find its azimuth; but if the point is *above* the horizon, then its azimuth is estimated by passing a vertical circle through it, and reckoning the azimuth from the point where this circle cuts the horizon.

The *Zenith Distance* of a body is measured on a vertical circle, passing through that body. It is the complement of the altitude.

15. The *Axis of the Earth* is the diameter, on which the earth is conceived to turn in its diurnal revolution. The same line continued until it meets the starry concave, constitutes the *axis of the celestial sphere.*

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14. Define *vertical* circles—the *meridian*—the *prime vertical*—*altitude*—*azimuth*—*amplitude*. How many degrees of azimuth are reckoned? from what points? How are azimuth and amplitude related to each other? Define *zenith distance*—How is it related to the altitude?

15. Define the *axis of the earth*—the axis of the celestial sphere—the poles of the earth—the poles of the heavens.

The *Poles of the Earth* are the extremities of the earth's axis: *the Poles of the Heavens*, the extremities of the celestial axis.

16. The *Equator* is a great circle cutting the axis of the earth at right angles. Hence the axis of the earth is the axis of the equator, and its poles are the poles of the equator. The intersection of the plane of the equator with the surface of the earth, constitutes the *terrestrial*, and with the concave sphere of the heavens, the *celestial* equator. The latter, by way of distinction, is sometimes denominated the *equinoctial.*

17. The secondaries to the equator, that is, the great circles passing through the poles of the equator, are called *Meridians*, because that secondary which passes through the zenith of any place is the meridian of that place, and is at right angles both to the equator and the horizon, passing as it does through the poles of both. These secondaries are also called *Hour Circles*, because the arcs of the equator intercepted between them are used as measures of time.

18. The *Latitude* of a place on the earth, is its distance from the equator north or south. The *Polar Distance*, or angular distance from the nearest pole, is the complement of the latitude.

19. The *Longitude* of a place is its distance from some standard meridian, either east or west, measured on the equator. The meridian usually taken as the standard, is that of the Observatory of Greenwich, in London. If a place is directly *on* the equator, we have only to inquire how many degrees of the equator there

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16. Define the equator. What constitutes the terrestrial equator? what the celestial equator? What is this also called?
17. What are the secondaries of the equator called?
18. Define the Latitude of a place—the polar distance.

are between that place and the point where the meridian of Greenwich cuts the equator. If the place is north or south of the equator, then its longitude is the arc of the equator intercepted between the meridian which passes through the place, and the meridian of Greenwich.

20. The *Ecliptic* is a great circle in which the earth performs its annual revolution around the sun. It passes through the center of the earth and the center of the sun. It is found by observation that the earth does not lie with its axis at right angles to the plane of the ecliptic, but that it is turned about $23\frac{1}{2}$ degrees out of a perpendicular direction, making an angle with the plane itself of $66\frac{1}{2}°$. The equator, therefore, must be turned the same distance out of a coincidence with the ecliptic, the two circles making an angle with each other of $23\frac{1}{2}°$. It is particularly important for the learner to form correct ideas of the ecliptic, and of its relations to the equator, since to these two circles a great number of astronomical measurements and phenomena are referred.

21. The *Equinoctial Points*, or *Equinoxes*,* are the intersections of the ecliptic and equator. The time when the sun crosses the equator in going northward is called the *vernal*, and in returning southward, the *autumnal* equinox. The vernal equinox occurs about the 21st of March, and the autumnal the 22d of September.

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19. Define the Longitude of a place. What is the standard meridian? When a place is *on* the equator, how is its longitude measured? how when it is *north* or *south* of the equator?

20. Define the ecliptic. How does it pass with respect to the earth and the sun? How is it situated with respect to the equator?

21. Define the equinoctial points. When is the vernal equinox, and when the autumnal?

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* The term Equinoxes strictly denotes the *times* when the sun arrives at the equinoctial points, but it is frequently used to denote those points themselves.

22. The *Solstitial Points* are the two points of the ecliptic most distant from the equator. The times when the sun comes to them are called *solstices.* The summer solstice occurs about the 22d of June, and the winter solstice about the 22d of December.

The ecliptic is divided into twelve equal parts of 30° each, called *signs*, which, beginning at the vernal equinox, succeed each other in the following order:

Northern.		*Southern.*	
1. Aries	♈	7. Libra	♎
2. Taurus	♉	8. Scorpio	♏
3. Gemini	♊	9. Sagittarius	♐
4. Cancer	♋	10. Capricornus	♑
5. Leo	♌	11. Aquarius	♒
6. Virgo	♍	12. Pisces	♓

The mode of reckoning on the ecliptic, is by signs, degrees, minutes, and seconds. The sign is denoted either by its name or its number. Thus 100° may be expressed either as the 10th degree of Cancer, or as 3^s 10°.

23. Of the various meridians, two are distinguished by the name of *Colures.* The *Equinoctial Colure*, is the meridian which passes through the equinoctial points. From this meridian, right ascension and celestial longitude are reckoned, as longitude on the earth is reckoned from the meridian of Greenwich. The *Solstitial Colure*, is the meridian which passes through the solstitial points.

24. The position of a celestial body is referred to the equator by its right ascension and declination. *Right*

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22. Define the solstitial points, and solstices. When does the summer solstice occur? when does the winter solstice occur? Into how many signs is the ecliptic divided? How many degrees are there in each? Name the signs. What is the mode of reckoning on the ecliptic? In what two ways may 100° be expressed?

23. What is the equinoctial colure?—the solstitial colure?

Ascension, is the angular distance from the vernal equinox measured on the equator. If a star is situated *on* the equator, then its right ascension is the number of degrees of the equator between the star and the vernal equinox. But if the star is north or south of the equator, then its right ascension is the arc of the equator, intercepted between the vernal equinox and that secondary to the equator which passes through the star. *Declination* is the distance of a body from the equator, measured on a secondary to the latter. Therefore, right ascension and declination correspond to terrestrial longitude and latitude, right ascension being reckoned from the equinoctial colure, in the same manner as longitude is reckoned from the meridian of Greenwich. On the other hand, celestial longitude and latitude are referred, not to the equator, but to the ecliptic. *Celestial Longitude*, is the distance of a body from the vernal equinox reckoned on the ecliptic. *Celestial Latitude*, is distance from the ecliptic measured on a secondary to the latter. Or, more briefly, Longitude is distance *on* the ecliptic; Latitude, distance *from* the ecliptic. The *North Polar Distance* of a star, is the complement of its declination.

25. *Parallels of Latitude* are small circles parallel to the equator. They constantly diminish in size as we go from the equator to the pole.

The *Tropics* are the parallels of latitude that pass through the solstices. The northern tropic is called the tropic of Cancer; the southern, the tropic of Capricorn.

The *Polar Circles* are the parallels of latitude that pass through the poles of the ecliptic, at the distance of $23\frac{1}{2}$ degrees from the pole of the earth.

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24. Define right ascension and declination. To what do they correspond on the terrestrial sphere? Define celestial longitude and latitude.

25. What are parallels of latitude—tropics—polar circles? To what is the elevation of the pole always equal? also that of the equator?

The *elevation of the pole* of the heavens above the horizon of any place, is always equal to the latitude of the place. Thus, in 40° of north latitude we see the north star 40° above the northern horizon, whereas, if we should travel southward its elevation would grow less and less, until we reached the equator, where it would appear in the horizon; or, if we should travel northward, the north star would rise constantly higher and higher, until, if we could reach the pole of the earth, that star would appear directly over head. The *elevation of the equator* above the horizon of any place, is equal to the complement of the latitude. Thus, at the latitude of 40° N. the equator is elevated 50° above the southern horizon.

26. The earth is divided into five zones. That portion of the earth which lies between the tropics, is called the *Torrid Zone;* that between the tropics and polar circles, the *Temperate Zones;* and that between the polar circles and the poles, the *Frigid Zones.*

27. The *Zodiac* is the part of the celestial sphere, which lies about 8 degrees on each side of the ecliptic. This portion of the heavens is thus marked off by itself, because all the planets move within it.

28. After endeavoring to form, from the definitions, as clear an idea as he can of the various circles of the sphere, the learner may next resort to an artificial globe, and see how they are severally represented there. Or if he has not access to a globe, he may aid his conceptions by the following easy device. To represent the earth, select a large *apple*, (a melon when in season will be found still better.) The shape of the apple, flattened as

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26. Define each of the zones.

27. Define the zodiac.

28. Show how to represent the artificial sphere by any round body, as an apple, and point out the various circles on it.

it usually is at the two ends, will not inaptly exhibit the spheroidal figure of the earth, while the larger diameter through the middle will indicate the excess of matter about the equator; although we should remark, that the disproportion between the polar and equatorial diameters of the earth is in fact so slight, that it would be scarcely perceptible in a model. The eye and the stem of the apple will indicate the position of the two poles of the earth. Applying the thumb and finger of the left hand to the poles, and holding the apple so that the poles may be in a north and south line, turn the globe from west to east, and its motion will correspond to the diurnal movement of the globe. Pass a wire, as a knitting needle, through the poles, and it will represent the *axis* of the sphere. A circle cut around the apple half way between the poles, will be the *equator;* and several other circles cut between the equator and the poles, parallel to the equator, will represent *parallels of latitude*, of which, two drawn $23\frac{1}{2}$ degrees from the equator, will be the *tropics*, and two others at the same distance from the poles, will be the *polar circles.* A great circle cut through the poles in a north and south direction, will form the *meridian*, and several other great circles drawn through the poles, and of course perpendicularly to the equator, will be secondaries to the equator, constituting meridians or *hour circles.* A great circle cut through the center of the earth from one tropic to the other, will represent the *plane* of the ecliptic, and consequently, a line cut around the apple where such a section meets the surface, is the terrestrial *ecliptic.* The points where this circle meets the tropics, are the *solstices*, and its intersections with the equator are the *equinoctial points.*

29. The *horizon* is best represented by a circular piece of pasteboard, cut so as to fit closely to the apple, being movable upon it. When this horizon is slipped

29. How is the horizon represented in our model? How is it placed to represent the horizon of the equator? How for the horizon of the poles? How for our own horizon? How shall we represent the prime vertical?

up to the poles, it becomes the horizon of the equator; when it is so placed as to coincide with the earth's equator, it becomes the horizon of the poles; and in every other situation it represents the horizon of a place on the globe 90° every way from it. Suppose we are in latitude 40°, then let us place our movable paper parallel to our own horizon, and elevate the pole 40° above it, as near as we can judge by the eye. If we cut a circle around the apple, passing through its highest parts and through the east and west points, it will represent the *prime vertical*.

30. We cannot too strongly recommend to the young learner to form for himself such a sphere as is here described, and to point out on it the various arcs of azimuth and altitude, right ascension and declination, terrestrial and celestial latitude and longitude, these last being referred to the equator on the earth, and to the ecliptic in the heavens.

31. When the circles of the sphere are well learned, we may advantageously employ projections of them in various illustrations. By the *projection of the sphere* is meant a representation of all its parts on a plane. The plane itself is called the plane of projection. Let us take any circular ring, as a wire bent into a circle, and hold it in different positions before the eye. If we hold it parallel to the face, or directly opposite to the eye, we see it as an entire circle. If we turn it a little sideways, it appears oval, or as an ellipse; and as we continue to turn it more and more round, the ellipse grows narrower and narrower, until, when the edge is presented to the eye, we see nothing but a line. Now imagine the ring to be near a perpendicular wall, and the eye to be re-

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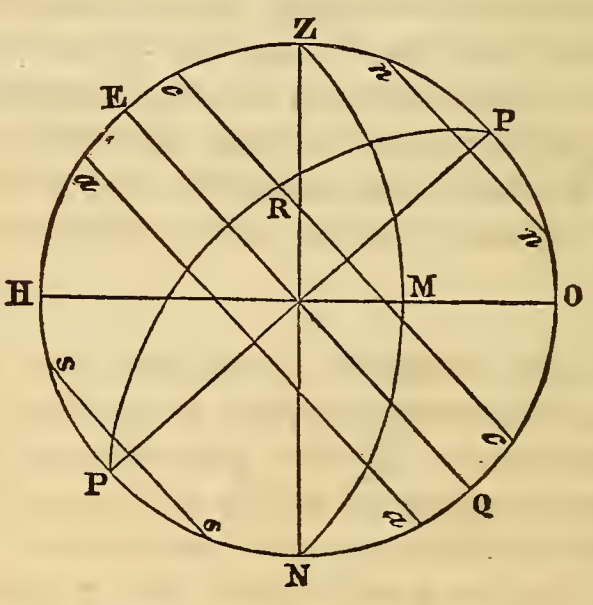
30. What is particularly recommended to the young learner?

31 What is meant by the projection of the sphere? What is the projection of a circle when seen directly before the face? what when seen obliquely? what when seen edgewise?

moved at such a distance from it, as not to distinguish any interval between the ring and the wall; then the several figures under which the ring is seen, will appear to be inscribed on the wall, and we shall see the ring as a circle when perpendicular to a straight line joining the center of the ring and the eye, as an ellipse when oblique to this line, or as a straight line when its edge is towards us.

32. It is in this manner that the circles of the sphere are projected, as represented in the following diagram

Fig. 5.



Here various circles are represented as projected on the meridian, which is supposed to be situated directly before the eye, at some distance from it. The horizon HO being perpendicular to the meridian is seen edgewise, and consequently is projected into a straight line. The same is the case with the prime vertical ZN, with the equator EQ, and the several small circles parallel to the equator, which represent the two tropics and the two polar cir-

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32. In figure 5, what represents the plane of projection? Why are certain circles represented by straight lines? why are others represented by ellipses? How is the eye supposed to be situated?

cles. In fact, all circles whatsoever, which are perpendicular to the plane of projection, will be represented by straight lines. But every circle which is perpendicular to the horizon, except the prime vertical, being seen obliquely as ZMN, will be projected into an ellipse. In the same manner, PRP, an hour circle, being oblique to the eye, is represented by an ellipse on the plane of projection.

CHAPTER II.

DIURNAL REVOLUTION—ARTIFICIAL GLOBES.

33. The apparent diurnal revolution of the heavenly bodies from east to west, is owing to the actual revolution of the earth on its own axis from west to east. If we conceive of a radius of the earth's equator extended until it meets the concave sphere of the heavens, then as the earth revolves, the extremity of this line would trace out a curve on the face of the sky, namely, the celestial equator. In curves parallel to this, called the *circles of diurnal revolution*, the heavenly bodies actually *appear* to move, every star having its own peculiar circle. After the learner has first rendered familiar the real motions of the earth from west to east, he may then, without danger of misconception, adopt the common language, that all the heavenly bodies revolve around the earth once a day from east to west, in circles parallel to the equator and to each other.

34. The time occupied by a star in passing from any point in the meridian until it comes round to the same

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33. To what is the apparent diurnal revolution of the heavenly bodies from east to west owing? If a radius of the earth's equator were extended to meet the concave sphere of the heavens, what would it trace out as the earth revolves? What are circles of diurnal revolution?

point again, is called a *sidereal day*, and measures the period of the earth's revolution on its axis. If we watch the returns of the same star from day to day, we shall find the intervals exactly equal to one another; that is, *the sidereal days are all equal.* Whatever star we select for the observation, the same result will be obtained. The stars, therefore, always keep the same relative position, and have a common movement round the earth—a consequence that naturally flows from the hypothesis, that their *apparent* motion is all produced by a single *real* motion, namely, that of the earth. The sun, moon, and planets, as well the fixed stars, revolve in like manner, but their returns to the meridian are not, like those of the fixed stars, at exactly equal intervals.

35. The *appearances* of the diurnal motions of the heavenly bodies are different in different parts of the earth, since every place has its own horizon, (Art. 8,) and different horizons are variously inclined to each other. Let us suppose the spectator viewing the diurnal revolutions from several different positions on the earth. On the *equator*, his horizon would pass through both poles; for the horizon cuts the celestial vault at 90 degrees in every direction from the zenith of the spectator; but the pole is likewise 90 degrees from his zenith, and consequently, the pole must be in the horizon. The celestial equator would coincide with the Prime Vertical,

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34. Define a *sidereal day.* Are the sidereal days equal or unequal? Are the returns of the sun, moon, and planets to the meridian, likewise at equal intervals?

35. How are the appearances of the diurnal motions in different parts of the earth? When the spectator is on the equator, where would his horizon pass with respect to the poles of the earth? With what great circle would the celestial equator coincide? How would all the circles of diurnal revolution be situated with respect to the horizon? Define a *right sphere.* In a right sphere, how would a star situated in the celestial equator perform its circuit? how would stars nearer the poles appear to move?

being a great circle passing through the east and west points. Since all the diurnal circles are parallel to the equator, consequently, they would all, like the equator, be perpendicular to the horizon. Such a view of the heavenly bodies, is called a right sphere ; or,

A RIGHT SPHERE *is one in which all the daily revolutions of the stars, are in circles perpendicular to the horizon.*

A right sphere is seen only at the equator. Any star situated in the celestial equator, would appear to rise directly in the east, when on the meridian to be in the zenith of the spectator, and to set directly in the west; in proportion as stars are at a greater distance from the equator towards the pole, they describe smaller and smaller circles, until near the pole, their motion is hardly perceptible.

36. If the spectator advances one degree towards the north pole, his horizon reaches one degree beyond the pole of the earth, and cuts the starry sphere one degree below the pole of the heavens, or below the north star, if that be taken as the place of the pole. As he moves onward towards the pole, his horizon continually reaches farther and farther beyond it, until when he comes to the pole of the earth, and under the pole of the heavens, his horizon reaches on all sides to the equator and coincides with it. Moreover, since all the circles of daily motion are parallel to the equator, they become, to the spectator at the pole, parallel to the horizon. This is what constitutes a parallel sphere. Or,

A PARALLEL SPHERE *is that in which all the circles of daily motion are parallel to the horizon.*

To render this view of the heavens familiar, the learner should follow round in his mind a number of

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36. What changes take place in one's horizon as he moves from the equator towards the pole ? How would it be situated when he reached the pole ? Define a *parallel sphere.* Explain the appearances of the stars and of the sun in a parallel sphere. Where only can such a sphere be seen ? Has the pole of the earth ever been reached by man ?

separate stars, one near the horizon, one a few degrees above it, and a third near the zenith. To one who stood upon the north pole, the stars of the northern hemisphere would all be perpetually in view when not obscured by clouds or lost in the sun's light, and none of those of the southern hemisphere would ever be seen. The sun would be constantly above the horizon for six months in the year, and the remaining six constantly out of sight. That is, at the pole the days and nights are each six months long. The phenomena at the south pole are similar to those at the north.

A perfect parallel sphere can never be seen except at one of the poles—a point which has never been actually reached by man; yet the British discovery ships penetrated within a few degrees of the north pole, and of course enjoyed the view of a sphere nearly parallel.

37. As the circles of daily motion are parallel to the horizon of the pole, and perpendicular to that of the equator, so at all places between the two, the diurnal motions are oblique to the horizon. This aspect of the heavens constitutes an oblique sphere, which is thus defined:

An Oblique Sphere *is that in which the circles of daily motion are oblique to the horizon.*

Suppose, for example, the spectator is at the latitude of fifty degrees. His horizon reaches 50° beyond the pole of the earth, and gives the same apparent elevation to the pole of the heavens. It cuts the equator, and all the circles of daily motion, at an angle of 40°, being always equal to the co-altitude of the pole. Thus, let HO (Fig. 6,) represent the horizon, EQ the equator, and PP′ the axis of the earth. Also, *ll*, *mm*, &c., parallels of latitude. Then the horizon of a spectator at Z, in latitude 50° reaches to 50° beyond the pole; and the angle ECH, is 40°. As we advance still farther north

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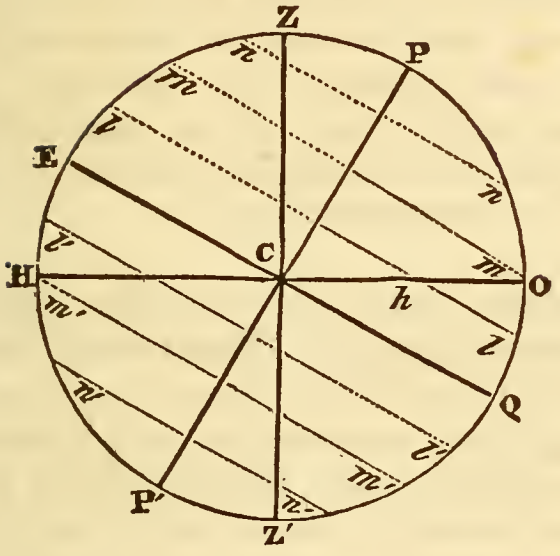
37. Define an *oblique sphere*. Where is it seen? At the latitude of 50° how is the horizon situated? Illustrate by fig. 6

Fig. 6.



the elevation of the diurnal circles grows less and less, and consequently the motions of the heavenly bodies more and more oblique, until finally, at the pole, where the latitude is 90°, the angle of elevation of the equator vanishes, and the horizon and equator coincide with each other, as before stated.

38. The CIRCLE OF PERPETUAL APPARITION, *is the boundary of that space around the elevated pole, where the stars never set.* Its distance from the pole is equal to the latitude of the place. For, since the altitude of the pole is equal to the latitude, a star whose polar distance is just equal to the latitude, will when at its lowest point only just reach the horizon; and all the stars nearer the pole than this will evidently not descend so far as the horizon.

Thus, *mm* (Fig. 6,) is the circle of perpetual apparition, between which and the north pole, the stars never set, and its distance from the pole OP is evidently equal to the elevation of the pole, and of course to the latitude.

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38. What is the circle of perpetual apparition? Illustrate by fig. 6.

39. In the opposite hemisphere, a similar part of the sphere adjacent to the depressed pole never rises. Hence, (*The* CIRCLE OF PERPETUAL OCCULTATION, *is the boundary of that space around the depressed pole, within which the stars never rise.*) Thus, *m'm'* (Fig. 6,) is the circle of perpetual occultation, between which and the south pole, the stars never rise.

40. (In an oblique sphere, the horizon cuts the circles of daily motion unequally. Towards the elevated pole, more than half the circle is above the horizon, and a greater and greater portion as the distance from the equator is increased, until finally, within the circle of perpetual apparition, the whole circle is above the horizon. Just the opposite takes place in the hemisphere next the depressed pole. (Accordingly, when the sun is in the equator, as the equator and horizon, like all other great circles of the sphere, bisect each other, the days and nights are equal all over the globe.) (But when the sun is north of the equator, the days become longer than the nights, but shorter when the sun is south of the equator.) Moreover, the higher the latitude, the greater is the inequality in the lengths of the days and nights. All these points will be readily understood by inspecting figure 6.

41. Most of the appearances of the diurnal revolution can be explained, either on the supposition that the celestial sphere actually all turns around the earth once in 24 hours, or that this motion of the heavens is merely apparent, arising from the revolution of the earth on its

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39. What is the circle of perpetual occultation? Illustrate by fig. 6.

40. How does the horizon of an oblique sphere cut the circles of daily motion? Towards the elevated pole what portion of the circles is above the horizon? Towards the depressed pole, how is the fact? When are the days and nights equal all over the world? When are the days longer, and when shorter than the nights?

axis in the opposite direction—a motion of which we are insensible, as we sometimes lose the consciousness of our own motion in a ship or a steamboat, and observe all external objects to be receding from us with a common motion. Proofs entirely conclusive and satisfactory, establish the fact, that it is the earth and not the celestial sphere that turns; but these proofs are drawn from various sources, and the student is not prepared to appreciate their value, or even to understand some of them, until he has made considerable proficiency in the study of astronomy, and become familiar with a great variety of astronomical phenomena. To such a period of our course of instruction we therefore postpone the discussion of the hypothesis of the earth's rotation on its axis.

42. While we retain the same place on the earth, the diurnal revolution occasions no change in our horizon, but our horizon goes round as well as ourselves. Let us first take our station on the equator at sunrise; our horizon now passes through both the poles, and through the sun, which we are to conceive of as at a great distance from the earth, and therefore as cut, not by the terrestrial but by the celestial horizon. As the earth turns, the horizon dips more and more below the sun, at the rate of 15 degrees for every hour, and, as in the case of the polar star, the sun appears to rise at the same rate. In six hours, therefore, it is depressed 90 degrees below the sun, which brings us directly under the sun, which, for our present purpose, we may consider as having all the while maintained the same fixed position in space

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41. On what suppositions can the appearances of the diurnal revolution be explained? Is it the earth or the heavens that really move? Why is the discussion of this subject postponed?

42. Explain the true cause of the sun's appearing to rise and set, as observed at the equator. What is the position of the horizon at sunrise? What at six hours afterwards? What at the end of twelve hours? What at the end of eighteen hours?

The earth continues to turn, and in six hours more, it completely reverses the position of our horizon, so that the western part of the horizon which at sunrise was diametrically opposite to the sun now cuts the sun, and soon afterwards it rises above the level of the sun, and the sun sets. During the next twelve hours, the sun continues on the invisible side of the sphere, until the horizon returns to the position from which it started, and a new day begins.

43. Let us next contemplate the similar phenomena at the *poles*. Here the horizon, coinciding as it does with the equator, would cut the sun through its center, and the sun would appear to revolve along the surface of the sea, one-half above and the other half below the horizon. This supposes the sun in its annual revolution to be at one of the equinoxes. When the sun is north of the equator, it revolves continually round in a circle, which, during a single revolution, appears parallel to the equator, and it is constantly day; and when the sun is south of the equator, it is, for the same reason, continual night.

We have endeavored to conceive of the manner in which the apparent diurnal movements of the sun are *really* produced at two stations, namely, in the right sphere, and in the parallel sphere. These two cases being clearly understood, there will be little difficulty in applying a similar explanation to an oblique sphere.

ARTIFICIAL GLOBES.

44. Artificial globes are of two kinds, terrestrial and celestial. The first exhibits a miniature representation of the earth; the second, of the visible heavens; and both show the various circles by which the two spheres

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43. Explain the similar phenomena at the poles, first, when the sun is at the equinoxes, and secondly, when it is north and when it is south of the equator.

are respectively traversed. Since all globes are similar solid figures, a small globe, imagined to be situated at the center of the earth or of the celestial vault, may represent all the visible objects and artificial divisions of either sphere, and with great accuracy and just proportions, though on a scale greatly reduced. The study of artificial globes, therefore, cannot be too strongly recommended to the student of astronomy.*

45. An artificial globe is encompassed from north to south by a strong brass ring to represent the meridian of the place. This ring is made fast to the two poles and thus supports the globe, while it is itself supported in a vertical position by means of a frame, the ring being usually let into a socket in which it may be easily slid, so as to give any required elevation to the pole. The brass meridian is graduated each way from the equator to the pole 90°, to measure degrees of latitude or declination, according as the distance from the equator refers to a point on the earth or in the heavens. The horizon is represented by a broad zone, made broad for the convenience of carrying on it a circle of azimuth, another of amplitude, and a wide space on which are delineated the signs of the ecliptic, and the sun's place for every day in the year; not because these points have any special connexion with the horizon, but because this broad surface furnishes a convenient place for recording them.

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44. What does the terrestrial globe exhibit? What does the celestial globe? What do both show?

45. How is the *meridian* of the place represented? To what points is the brass meridian fastened? What supports the ring? How is it graduated? How is the *horizon* represented? Why is it made broad? What circles are inscribed on it?

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* It were desirable, indeed, that every student of the science should have a celestial globe, at least, constantly before him. One of a small size, as eight or nine inches, will answer the purpose, although globes of these dimensions cannot usually be relied on for nice measurements

46. *Hour Circles* are represented on the terrestrial globe by great circles drawn through the pole of the equator; but, on the celestial globe, corresponding circles pass through the poles of the ecliptic, constituting *circles of latitude*, while the brass meridian, being a secondary to the equinoctial, becomes an hour circle of any star which, by turning the globe, is brought under it.

47. The *Hour Index* is a small circle described around the pole of the equator, on which are marked the hours of the day. As this circle turns along with the globe, it makes a complete revolution in the same time with the equator; or, for any less period, the same number of degrees of this circle and of the equator pass under the meridian. Hence the hour index measures arcs of right ascension, 15° passing under the meridian every hour.

48. The *Quadrant of Altitude* is a flexible strip of brass, graduated into ninety equal parts, corresponding in length to degrees on the globe, so that when applied to the globe and bent so as closely to fit its surface, it measures the angular distance between any two points. When the zero, or the point where the graduation begins, is laid on the pole of any great circle, the 90th degree will reach to the circumference of that circle, and being therefore a great circle passing through the pole of another great circle, it becomes a secondary to the latter. Thus the quadrant of altitude may be used as a secondary to any great circle on the sphere; but it is used chiefly as a secondary to the horizon, the point

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46. How are *hour circles* represented on the terrestrial globe? How are *circles of latitude* represented on the celestial globe?

47. Describe the *hour index*. What does it measure?

48. What is the *quadrant of altitude?* How is it graduated? When the zero point is laid on the pole of any great circle, to what will the 90th degree reach? How may it be used as a secondary to any great circle? When screwed on the zenith what does it become? What arcs does it then measure?

marked 90° being screwed fast to the pole of the horizon, that is, the zenith, and the other end, marked 0, being slid along between the surface of the sphere and the wooden horizon. It thus becomes a vertical circle, *on* which to measure the altitude of any star through which it passes, or *from* which to measure the azimuth of the star, which is the arc of the horizon intercepted between the meridian and the quadrant of altitude passing through the star.

49. To *rectify the globe for any place*, the north pole must be elevated to the latitude of the place; then the equator and all the diurnal circles will have their due inclination in respect to the horizon; and, on turning the globe, every point on either globe will revolve as the same point does in nature; and the relative situations of all places will be the same as on the native spheres.

PROBLEMS ON THE TERRESTRIAL GLOBE.

50. *To find the Latitude and Longitude of a place:* Turn the globe so as to bring the place to the brass meridian; then the degree and minute on the meridian directly over the place will indicate its latitude, and the point of the equator under the meridian, will show its longitude.

Ex. What is the Latitude and Longitude of the city of New York?

51. *To find a place having its Latitude and Longitude given:* Bring to the brass meridian the point of the equator corresponding to the longitude, and then at the degree of the meridian denoting the latitude, the place will be found.

Ex. What place on the globe is in Latitude 39° N. and Longitude 77° W.?

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49. How do we *rectify the globe* for any place?
50. Find the latitude and longitude of Washington City.
51. What place lies in latitude 39° N. and longitude 77° W.?

52. *To find the bearing and distance of two places:* Rectify the globe for one of the places; screw the quadrant of altitude to the zenith,* and let it pass through the other place. Then the azimuth will give the bearing of the second place from the first, and the number of degrees on the quadrant of altitude, multiplied by 69, (the number of miles in a degree,) will give the distance between the two places.

Ex. What is the bearing of New Orleans from New York, and what is the distance between these places?

53. *To determine the difference of time in different places:* Bring the place that lies eastward of the other to the meridian, and set the hour index at XII. Turn the globe eastward until the other place comes to the meridian, then the index will point to the hour required.

Ex. When it is noon at New York, what time is it at London?

54. *The hour being given at any place, to tell what hour it is in any other part of the world:* Bring the given place to the meridian, and set the hour index to the given time; then turn the globe, until the other place comes under the meridian, and the index will point to the required hour.

Ex. What time is it at Canton, in China, when it is 9 o'clock A. M. at New York?

55. *To find what people on the earth live under us, having their noon at the time of our midnight:* Bring the place where we dwell to the meridian, and set the

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52. What is the bearing and distance of New Orleans from New York?

53. When it is noon at New York, what time is it at Pekin?

54. What time is it at London when it is noon at Boston?

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* The zenith will of course be the point of the meridian over the place.

hour index to XII; then turn the globe until the other XII comes under the meridian; the point under the same part of the meridian where we were before, will be the place sought.

Ex. Find what place is directly under New York.

56. *To find what people of the southern hemisphere are directly opposite to us:* Bring our place to the meridian; the place in the same latitude south, then under the meridian, will be the place in question.

Ex. What place in the southern hemisphere corresponds to New Haven?

57. *To find the antipodes of a place, or the people whose feet are exactly opposite to ours:* Bring our place to the meridian; set the hour index to XII, and turn the globe until the other XII comes under the meridian; then the point of the southern hemisphere under the meridian and having the same latitude with ours, will be the place of our antipodes.

Ex. Who are antipodes to the people of Philadelphia?

58. *To rectify the globe for the sun's place:* On the wooden horizon, find the day of the month, and against it is given the sun's place in the ecliptic, expressed by signs and degrees.* Look for the same sign and degree on the ecliptic, bring that point to the meridian and set the hour index to XII. To all places under the meridian it will then be noon.

Ex. Rectify the globe for the sun's place on the 1st of September.

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55. Find what place is directly under Philadelphia.
56. What place in south latitude corresponds to Boston?
57. Who are the antipodes of the people of London?
58. Rectify the globe for the sun's place for the first of June

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* The larger globes have the day of the month marked against the corresponding sign on the ecliptic itself.

59. *The latitude of the place being given, to find the time of the sun's rising and setting on any given day at that place:* Having rectified the globe for the latitude, bring the sun's place in the ecliptic to the graduated edge of the meridian, and set the hour index to XII; then turn the globe so as to bring the sun to the eastern and then to the western horizon, and the hour index will show the times of rising and setting respectively.

Ex. At what time will the sun rise and set at New Haven, Lat. 41° 18′, on the 10th of July?

PROBLEMS ON THE CELESTIAL GLOBE.

60. *To find the Declination and Right Ascension of a heavenly body:* Bring the place of the body (whether sun or star) to the meridian. Then the degree and minute standing over it will show its declination, and the point of the equinoctial under the meridian will give its right ascension. It will be remarked, that the declination and right ascension are found in the same manner as latitude and longitude on the terrestrial globe. Right ascension is expressed either in degrees or in hours; both being reckoned from the vernal equinox.

Ex. What is the declination and right ascension of the bright star Lyra?—also of the sun on the 5th of June?

61. *To represent the appearance of the heavens at any time:* Rectify the globe for the latitude, bring the sun's place in the ecliptic to the meridian, and set the hour index to XII; then turn the globe westward until the index points to the given hour, and the constellations would then have the same appearance to an eye situated

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59. Find the time of the sun's rising and setting at Boston (Lat. 42°, Lon. 71°) on the first day of December.

60. On the *celestial globe*, What is the right ascension and declination of any star taken at pleasure?

61. Represent the appearance of the heavens at Tuscaloosa (Lat. 33°, Lon. 87°) at 8 o'clock in the evening of Nov. 13th

at the center of the globe, as they have at that moment in the sky.

Ex. Required the aspect of the stars at New Haven, Lat. 41° 18′, at 10 o'clock, on the evening of December 5th.

62. *To find the altitude and azimuth of any star:* Rectify the globe for the latitude, and let the quadrant of altitude be screwed to the zenith, and be made to pass through the star. The arc on the quadrant, from the horizon to the star, will denote its altitude, and the arc of the horizon from the meridian to the quadrant, will be its azimuth.

Ex. What is the altitude and azimuth of Sirius (the brightest of the fixed stars) on the 25th of December at 10 o'clock in the evening, in Lat. 41°?

63. *To find the angular distance of two stars from each other:* Apply the zero mark of the quadrant of altitude to one of the stars, and the point of the quadrant which falls on the other star, will show the angular distance between the two.

Ex. What is the distance between the two largest stars of the Great Bear.*

64. *To find the sun's meridian altitude, the latitude and day of the month being given:* Having rectified the globe for the latitude, bring the sun's place in the ecliptic to the meridian, and count the number of de-

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62. Find the altitude and azimuth of Lyra at 10 o'clock in the evening of June 18th, in Lat. 42°.

63. Find the angular distance between any two stars taken at pleasure.

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* These two stars are sometimes called "the Pointers," from the line which passes through them being always nearly in the direction of the north star. The angular distance between them is about 5°, and may be learned as a standard of reference in estimating by the eye, the distance between any two points on the celestial vault.

grees and minutes between that point of the meridian and the zenith. The complement of this arc will be the sun's meridian altitude.

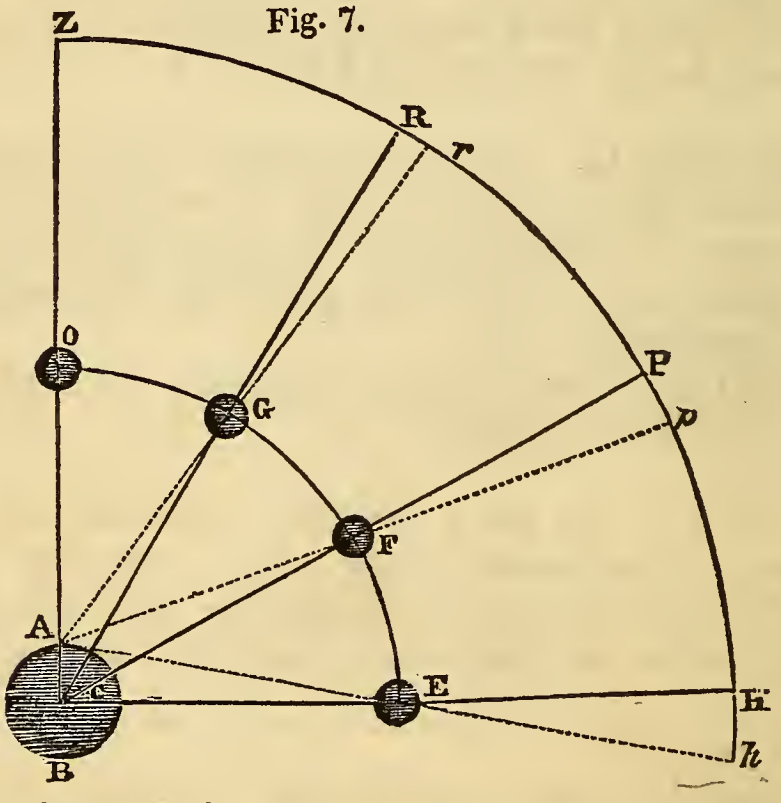
Ex. What is the sun's meridian altitude at noon on the 1st of August, in Lat. 41° 18′?

CHAPTER III.

OF PARALLAX, REFRACTION, AND TWILIGHT.

65. PARALLAX *is the apparent change of place which bodies undergo by being viewed from different points.*

Fig. 7.



Thus in figure 7, let A represent the earth, CH the horizon. HZ a quadrant of a great circle of the heavens,

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64. What is the sun's meridian altitude at noon on the 18th of June, in latitude 35°?

65. Define parallax. Illustrate by the figure. What angle measures the parallax? Why do astronomers consider the heavenly bodies as viewed from the center of the earth?

extending from the horizon to the zenith; and let E, F, G, O, be successive positions of the moon at different elevations, from the horizon to the meridian. Now a spectator on the surface of the earth at A, would refer the place of E to *h*, whereas, if seen from the center of the earth, it would appear at H. The arc H*h* is called the parallactic arc, and the angle HE*h*, or its equal AEC, is the angle of parallax. The same is true of the angles at F, G, and O, respectively.

Since then a heavenly body is liable to be referred to different points on the celestial vault, when seen from different parts of the earth, and thus some confusion occasioned in the determination of points on the celestial sphere, astronomers have agreed to consider the true place of a celestial object to be that, where it would appear if seen from the center of the earth. The doctrine of parallax teaches how to reduce observations made at any place on the surface of the earth, to such as hey would be if made from the center.

66. The angle AEC is called the horizonta parallax, which may be thus defined. *Horizontal Parallax*, is the change of position which a celestial body, appearing in the horizon as seen from the surface of the earth, would assume if viewed from the earth's center. It is the angle subtended by the semi-diameter of the earth, as viewed from the body itself.

It is evident from the figure, that the effect of parallax upon the place of a celestial body is *to depress it*. Thus, in consequence of parallax, E is depressed by the arc H*h*; F by the arc P*p*; G by the arc R*r*; while O sustains no change. Hence, in all observations on the altitude of the sun, moon, or planets, the amount of parallax is to be added: the stars, as we shall see hereafter, have no sensible parallax.

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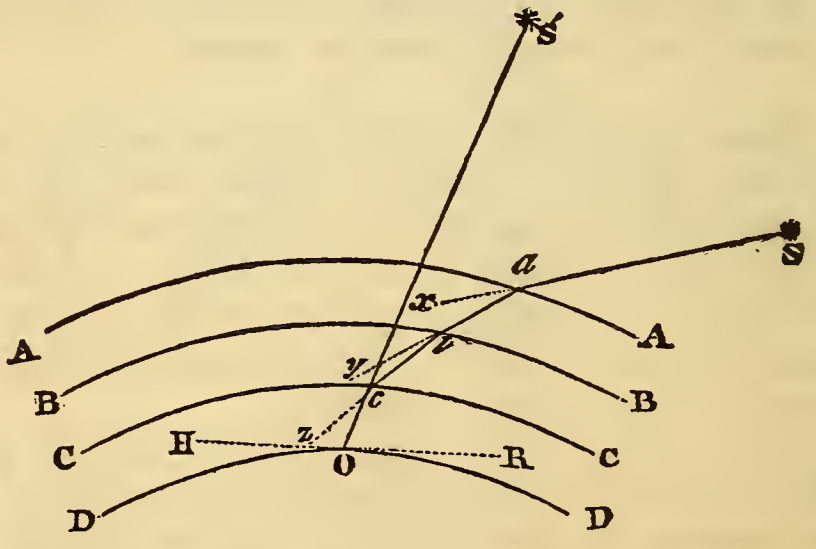
66. Define horizontal parallax—By what is it subtended? (See Art. 10. *Note.*) What is the effect of parallax upon the place of a heavenly body?

67. The determination of the horizontal parallax of a celestial body is an element of great importance, since it furnishes the means of estimating the distance of the body from the center of the earth. Thus, if the angle AEC (Fig 7,) be found, the radius of the earth AC being known, we have in the right angled triangle AEC, the side AC and all the angles, to find the side CE, which is the distance of the moon from the center of the earth.*

REFRACTION.

68. While parallax depresses the celestial bodies subject to it, *refraction elevates them*; and it affects alike the most distant as well as nearer bodies, being occasioned by the change of direction which light undergoes

Fig. 8.



67. Why is the determination of the parallax of a heavenly body an element of great importance? Illustrate by figure 7.

* Should the reader be unacquainted with the principles of trigonometry, yet he ought to know the *fact* that these principles enable us, when we have ascertained certain parts in a triangle, to find the unknown parts. Thus, in the above case, when we have found the angle of parallax, AEB, (which is determined by certain astronomical observations,) knowing also the semi-diameter of the earth AC, we can find by trigonometry, the length of the side CE, which is the distance of the body from the center of the earth.

in passing through the atmosphere. Let us conceive of the atmosphere as made up of a great number of concentric strata, as AA, BB, CC, and DD, (Fig. 8,) increasing rapidly in density (as is known to be the fact) in approaching near to the surface of the earth. Let S be a star, from which a ray of light S*a* enters the atmosphere at *a*, where, being much turned towards the radius of the convex surface,* it would change its direction into the line *ab*, and again into *bc*, and *c*O, reaching the eye at O. Now, since an object always appears in the direction in which the light finally strikes the eye, the star would be seen in the direction of the ray O*c*, and therefore, the star would apparently change its place, in consequence of refraction, from S to S′, being elevated out of its true position. Moreover, since on account of the continual increase of density in descending through the atmosphere, the light would be continually turned out of its course more and more, it would therefore move, not in the polygon represented in the figure, but in a corresponding curve, whose curvature is rapidly increased near the surface of the earth.

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68. What effect has refraction upon the place of a heavenly body? By what is it occasioned? Illustrate by figure 8. How is a ray of light affected by passing out of a rarer into a denser medium? Why is an oar bent in the water? In what line does the light move as it goes through the atmosphere?

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* The operation of this principle is seen when an oar, or any stick, is thrust into water. As the rays of light by which the oar is seen, have their direction changed as they pass out of water into air, the apparent direction in which the body is seen is changed in the same degree, giving it a bent appearance. Thus, in the figure, if S*ax* represents the oar, S*ab* will be the bent appearance as affected by refraction. The transparent substance through which any ray of light passes, is called a medium. It is a general fact in optics, that when light passes out of a rarer into a denser medium, as out of air into water, or out of space into air, it is turned *towards* a perpendicular to the surface of the medium, and when it passes out of a denser into a rarer medium, as out of water into air, it is turned *from* the perpendicular. In the above case the light, passing out of space into air, is turned towards the radius of the earth, this being perpendicular to the surface of the atmosphere; and it is turned more and more towards that radius the nearer it approaches to the earth, because the density of the air rapidly increases.

69. When a body is in the zenith, since a ray of light from it enters the atmosphere at right angles to the refracting medium, it suffers no refraction. Consequently, the position of the heavenly bodies, when in the zenith, is not changed by refraction, while, near the horizon, where a ray of light strikes the medium very obliquely, and traverses the atmosphere through its densest part, the refraction is greatest. The following numbers, taken at different altitudes, will show how rapidly refraction diminishes from the horizon upwards. The amount of refraction at the horizon is 34′ 00″. At different elevations it is as follows:

Elevation.	Refraction.	Elevation.	Refraction.
0° 10′	32′ 00″	30°	1′ 40″
0° 20′	30′ 00″	40°	1′ 09″
1° 00′	24′ 25″	45°	0′ 58″
5° 00′	10′ 00″	60°	0′ 33″
10° 00′	5′ 20″	80°	0′ 10″
20° 00′	2′ 39″	90°	0′ 00″

From this table it appears, that while refraction at the horizon is 34 minutes, at so small an elevation as only 10′ above the horizon it loses 2 minutes, more than the entire change from the elevation of 30° to the zenith. From the horizon to 1° above, the refraction is diminished nearly 10 minutes. The amount at the horizon, at 45°, and at 90°, respectively, is 34′, 58″, and 0. In finding the altitude of a heavenly body, the effect of parallax must be added, but that of refraction subtracted.

70. Since the whole amount of refraction near the horizon exceeds 33′, and the diameters of the sun and moon are severally less than this, these luminaries are in

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69. Has refraction any effect on a body in the zenith? Why not? When is the refraction greatest? What is the amount of refraction at the horizon? How much does it lose within 10′ of the horizon? What is the amount of refraction at an elevation of 45°?

view both before they have actually risen and after they have set.

The rapid increase of refraction near the horizon, is strikingly evinced by the *oval* figure which the sun assumes when near the horizon, and which is seen to the greatest advantage when light clouds enable us to view the solar disk. Were all parts of the sun equally raised by refraction, there would be no change of figure; but since the lower side is more refracted than the upper, the effect is to shorten the vertical diameter and thus to give the disk an oval form. This effect is particularly remarkable when the sun, at his rising or setting, is observed from the top of a mountain, or at an elevation near the sea shore; for in such situations the rays of light make a greater angle than ordinary, with a perpendicular to the refracting medium, and the amount of refraction is proportionally greater. In some cases of this kind, the shortening of the vertical diameter of the sun has been observed to amount to 6′, or about one fifth of the whole.

71. The apparent *enlargement of the sun and moon in the horizon*, arises from an optical illusion. These bodies in fact are not seen under so great an angle when in the horizon, as when on the meridian, for they are nearer to us in the latter case than in the former. The distance of the sun is indeed so great that it makes very little difference in his apparent diameter, whether he is viewed in the horizon or on the meridian; but with the moon the case is otherwise; its angular diameter, when measured with instruments, is perceptibly larger at the time of its culmination. Why then do the sun and moon appear so much larger when near the horizon? It

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70. What effect has refraction upon the appearances of the sun and moon when near rising or setting? Explain the oval figure of the sun when near the horizon. In what position of the spectator does this phenomenon appear most conspicuous? How much has the vertical diameter of the sun ever appeared to be shortened?

is owing to that general law, explained in optics, by which we judge of the magnitudes of distant objects, not merely by the angle they subtend at the eye, but also by our impressions respecting their distance, allowing, under a given angle, a greater magnitude as we imagine the distance of a body to be greater. Now, on account of the numerous objects usually in sight between us and the sun, when on the horizon, he appears much farther removed from us than when on the meridian, and we assign to him a proportionally greater magnitude. If we view the sun, in the two positions, through smoked glass, no such difference of size is observed, for here no objects are seen but the sun himself.

The extraordinary enlargement of the sun or moon, particularly the latter, when seen at its rising through a grove of trees, depends on a different principle. Through the various openings between the trees, we see different images of the sun or moon, a great number of which overlapping each other, swell the dimensions of the body under the most favourable circumstances, to a very unusual size.

TWILIGHT.

72. *Twilight* also is another phenomenon depending upon the agency of the earth's atmosphere. *It is that illumination of the sky which takes place just before sunrise, and which continues after sunset.* It is due partly to refraction and partly to reflexion, but mostly to the latter. While the sun is within 18° of the horizon, before it rises or after it sets, some portion of its light is conveyed to us by means of numerous reflections from

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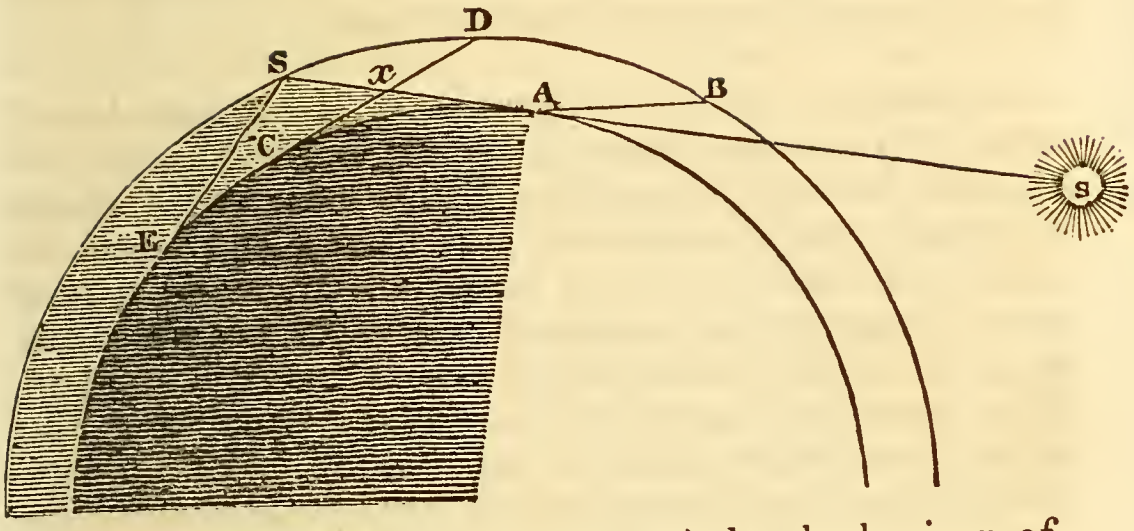
71. To what is the apparent enlargement of the sun and moon when near the horizon owing? Are these bodies seen under a greater angle when in the horizon than in the zenith? To what general law of optics is the enlargement to be ascribed? How is it when we view the sun through smoked glass? To what is the extraordinary enlargement of these luminaries owing, when seen through a grove of trees?

Fig. 9.



the atmosphere. Let AB (Fig. 9,) be the horizon of the spectator at A, and let SS be a ray of light from the sun when it is two or three degrees below the horizon. Then to the observer at A, the segment of the atmosphere ABS would be illuminated. To a spectator at C, whose horizon was CD, the small segment SDx would be the twilight; while, at E, the twilight would disappear altogether.

73. At the equator, where the circles of daily motion are perpendicular to the horizon, the sun descends through 18° in an hour and twelve minutes ($\frac{18}{15}=1\frac{1}{5}$h.), and the light of day therefore declines rapidly, and as rapidly advances after day break in the morning. At the pole, a constant twilight is enjoyed while the sun is within 18° of the horizon, occupying nearly two-thirds of the half year when the direct light of the sun is withdrawn, so that the progress from continual day to con-

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72. Define twilight—How many degrees below the horizon is the sun when it begins and ends? How is the light of the sun conveyed to us? Explain by the figure.

73. What is the length of twilight at the equator? How long does it last at the poles? How is the progress from continual day to constant night? To the inhabitants of an oblique sphere, in what latitudes is twilight longest?

stant night is exceedingly gradual. To the inhabitants of an oblique sphere, the twilight is longer in proportion as the place is nearer the elevated pole.

74. Were it not for the power the atmosphere has of dispersing the solar light, and scattering it in various directions, no objects would be visible to us out of direct sunshine; every shadow of a passing cloud would be pitchy darkness; the stars would be visible all day, and every apartment into which the sun had not direct admission, would be involved in the obscurity of night. This scattering action of the atmosphere on the solar light, is greatly increased by the irregularity of temperature caused by the sun, which throws the atmosphere into a constant state of undulation, and by thus bringing together masses of air of different temperatures, produces partial reflections and refractions at their common boundaries, by which means much light is turned aside from the direct course, and diverted to the purposes of general illumination. In the upper regions of the atmosphere, as on the tops of very high mountains, where the air is too much rarefied to reflect much light, the sky assumes a black appearance, and stars become visible in the dav time.

CHAPTER IV.

OF TIME.

75. TIME *is a measured portion of indefinite duration.** The great standard of time is the period of the revolution of the earth on its axis, which, by the most exact

74. What would happen were it not for the power the atmosphere has of dispersing the solar light? What would every shadow of a cloud produce? How is the scattering action of the atmosphere increased? What is the aspect of the sky in the upper regions of the atmosphere?

* From old Eternity's mysterious orb,
Was Time cut off and cast beneath the skies.—*Young.*

observations, is found to be always the same. The time of the earth's revolution on its axis is called a *sidereal day*, and is determined by the revolution of a star from the instant it crosses the meridian, until it comes round to the meridian again. This interval being called a sidereal day, it is divided into 24 *sidereal hours*. Observations taken upon numerous stars, in different ages of the world, show that they all perform their diurnal revolutions in the same time, and that their motion during any part of the revolution is perfectly uniform.

76. *Solar time* is reckoned by the apparent revolution of the sun, from the meridian round to the same meridian again. Were the sun stationary in the heavens, like a fixed star, the time of its apparent revolution would be equal to the revolution of the earth on its axis, and the solar and the sidereal days would be equal. But since the sun passes from west to east, through 360° in $365\frac{1}{4}$ days, it moves eastward nearly 1° a day, (59′ 8″.3). While, therefore, the earth is turning round on its axis, the sun is moving in the same direction, so that when we have come round under the same celestial meridian from which we started, we do not find the sun there, but he has moved eastward nearly a degree, and the earth must perform so much more than one complete revolution, in order to come under the sun again. Now since a place on the earth gains 359° in 24 hours, how long will it take to gain 1°?

$$359 : 24 :: 1 : \frac{24}{359} = 4^{m} \text{ nearly.}$$

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75. Define time—What is the standard of time? What is a sidereal day? Do the stars all perform their revolutions in the same time? Is their motion uniform?

76. How is the solar time reckoned? How far does the sun move eastward in a day? How much longer is the solar than the sidereal day? If we reckoned the sidereal day 24 hours, how should we reckon the solar? Reckoning the solar day at 24 hours, how long is the sidereal?

Hence the solar day is about 4 minutes longer than the sidereal; and if we were to reckon the sidereal day 24 hours, we should reckon the solar day 24h. 4m. To suit the purposes of society at large, however, it is found most convenient to reckon the solar day 24 hours, and to throw the fraction into the sidereal day. Then,

24h 4m. : 24 :: 24 : 23h. 56m. nearly (23h. 56^m $4^s.09$) = the length of a sidereal day.

77. The solar days, however, do not always differ from the sidereal by precisely the same fraction, since the increments of right ascension, which measure the difference between a sidereal and a solar day, are not equal to each other. *Apparent time*, is time reckoned by the revolutions of the sun from the meridian to the meridian again. These intervals being unequal, of course the apparent solar days are unequal to each other.

78. *Mean time*, is time reckoned by the *average* length of all the solar days throughout the year. This is the period which constitutes the civil day of 24 hours, beginning when the sun is on the lower meridian, namely, at 12 o'clock at night, and counted by 12 hours from the lower to the upper culmination, and from the upper to the lower. The *astronomical* day is the apparent solar day counted through the whole 24 hours, instead of by periods of 12 hours each, and begins at noon. Thus 10 days and 14 hours of astronomical time, would be 11 days and 2 hours of apparent time; for when the 10th astronomical day begins, it is 10 days and 12 hours of civil time.

79. Clocks are usually regulated so as to indicate mean solar time; yet as this is an artificial period, not marked

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77. Do the solar days always differ from the sidereal by the same quantity? Define apparent time.

78. Define mean time. What constitutes the civil day? What makes an astronomical day? When does the civil day begin? When does the astronomical day begin?

off, like the sidereal day, by any natural event, it is necessary to know how much is to be added to or subtracted from the apparent solar time, in order to give the corresponding mean time. The interval by which apparent time differs from mean time, is called the *equation of time*. If a clock were constructed (as it may be) so as to keep exactly with the sun, going faster or slower according as the increments of right ascension were greater or smaller, and another clock were regulated to mean time, then the difference of the two clocks, at any period, would be the equation of time for that moment.

If the apparent clock were *faster* than the mean, then the equation of time must be subtracted; but if the apparent clock were *slower* than the mean, then the equation of time must be added, to give the mean time. The two clocks would differ most about the 3d of November, when the apparent time is $16\frac{1}{4}^{m}$ greater than the mean (16^{m} $16^{s}.7$). But, since apparent time is sometimes greater and sometimes less than mean time, the two must obviously be sometimes equal to each other. This is in fact the case four times a year, namely, April 15th, June 15th, September 1st, and December 24th.

THE CALENDAR.

80. The *astronomical year* is the time in which the sun makes one revolution in the ecliptic, and consists of 365d. 5h. 48m. $51^{s}.60$. The *civil year* consists of 365 days. The difference is nearly 6 hours, making one day in four years.

The most ancient nations determined the number of days in the year by means of the *stylus*, a perpendicular

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79 What time do clocks commonly keep? Define the equation of time. How might two clocks be regulated so that their difference would indicate the equation of time? How must the equation of time be applied when the apparent clock is faster than the mean? How when it is slower? When would the two clocks differ most? How much would they then differ? When would they come together?

rod which casts its shadow on a smooth plane, bearing a meridian line. The time when the shadow was shortest, would indicate the day of the summer solstice; and the number of days which elapsed until the shadow returned to the same length again, would show the number of days in the year. This was found to be 365 whole days, and accordingly this period was adopted for the civil year. Such a difference, however, between the civil and astronomical years, at length threw all dates into confusion. For, if at first the summer solstice happened on the 21st of June, at the end of four years, the sun would not have reached the solstice until the 22d of June, that is, it would have been behind its time. At the end of the next four years the solstice would fall on the 23d; and in process of time it would fall successively on every day of the year. The same would be true of any other fixed date. Julius Cæsar made the first correction of the calendar, by introducing an intercalary day every fourth year, making February to consist of 29 instead of 28 days, and of course the whole year to consist of 366 days. This fourth year was denominated *Bissextile*. It is also called Leap Year.

81. But the true correction was not 6 hours, but 5h 49m.; hence the intercalation was too great by 11 minutes. This small fraction would amount in 100 years to $\frac{3}{4}$ of a day, and in 1000 years to more than 7 days. From the year 325 to 1582, it had in fact amounted to about 10 days; for it was known that in 325, the vernal equinox fell on the 21st of March, whereas, in 1582 it fell on the 11th. In order to restore the equinox to the same date, Pope Gregory XIII, decreed, that the year

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80. Define the astronomical year—What is its exact period? Of how many days does the civil year consist? How much shorter is the civil than the astronomical year? How did the most ancient nations determine the number of days in the year? When would the stylus mark the shortest day and when the longest? Explain the confusion which arose by reckoning the year only 365 days. How did Julius Cæsar reform the calendar?

should be brought forward 10 days, by reckoning the 5th of October the 15th. In order to prevent the calendar from falling into confusion afterwards, the following rule was adopted:

Every year whose number is not divisible by 4 *without a remainder, consists of* 365 *days; every year which is so divisible, but is not divisible by* 100, *of* 366; *every year divisible by* 100 *but not by* 400, *again of* 365; *and every year divisible by* 400, *of* 366.

Thus the year 1838, not being divisible by 4, contains 365 days, while 1836 and 1840 are leap years. Yet to make every fourth year consist of 366 days would increase it too much by about $\frac{3}{4}$ of a day in 100 years; therefore every hundredth year has only 365 days. Thus 1800, although divisible by 4 was not a leap year, but a common year. But we have allowed a *whole* day in a hundred years, whereas we ought to have allowed only *three fourths* of a day. Hence, in 400 years we should allow a day too much, and therefore we let the 400th year remain a leap year. This rule involves an error of less than a day in 4237 years. If the rule were extended by making every year divisible by 4000 (which would now consist of 366 days) to consist of 365 days, the error would not be more than one day in 100,000 years.

82. This reformation of the calendar was not adopted in England until 1752, by which time the error in the Julian calendar amounted to about 11 days. The year was brought forward, by reckoning the 3d of September the 14th. Previous to that time the year began the 25th

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81. By how many minutes was the allowance made by the Julian calendar too great? To how much would the error amount in one hundred years? To how much in a thousand years? To how much had it amounted from the year 325 to 1582? What changes did Pope Gregory make in the year? State the rule for the calendar. Of the three years 1836, 1838, and 1840, which are leap years? Was 1800 a leap year? How is every 400th year?

of March; but it was now made to begin on the 1st of January, thus shortening the preceding year, 1751, one quarter.*

As in the year 1582, the error in the Julian calendar amounted to 10 days, and increased by $\frac{3}{4}$ of a day in a century, at present the correction is 12 days; and the number of the year will differ by one with respect to dates between the 1st of January and the 25th of March.

Examples. General Washington was born Feb. 11 1731, old style; to what date does this correspond in new style?

As the date is the earlier part of the 18th century, the correction is 11 days, which makes the birth day fall on the 22d of February; and since the year 1731 closed the 25th of March, while according to new style 1732 would have commenced on the preceding 1st of January; therefore, the time required is Feb. 22, 1732. It is usual, in such cases, to write both years, thus: Feb. 11, 1731–2, O. S.

2. A great eclipse of the sun happened May 15th, 1836; to what date would this time correspond in old style? Ans. May 3d.

83. *The common year begins and ends on the same day of the week; but leap year ends one day later in the week than it began.*

For $52 \times 7 = 364$ days; if therefore the year begins on Tuesday, for example, 364 days would complete 52 weeks, and one day would be left to begin another week,

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82. When was this reformation first adopted in England? How was the year brought forward? When did the year begin before that time? To how many days did the error amount in 1752? How many days are allowed at present between old and new style?

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* Russia, and the Greek Church generally, adhere to the old style. In order to make the Russian dates correspond to ours, we must add to them 12 days. France and other Catholic countries, adopted the Gregorian calendar soon after it was promulgated

and the following year would begin on Wednesday. Hence, any day of the month is one day later in the week than the corresponding day of the preceding year. Thus, if the 16th of November, 1838, falls on Friday, the 16th of November, 1837, fell on Thursday, and in 1839 will fall on Saturday. But if leap year begins on Sunday, it ends on Monday, and the following year begins on Tuesday; while any given day of the month is two days later in the week than the corresponding date of the preceding year.

CHAPTER V.

OF ASTRONOMICAL INSTRUMENTS—FIGURE AND DENSITY OF THE EARTH.

84. The most ancient astronomers employed no instruments of observation, but acquired their knowledge of the heavenly bodies by long continued and most attentive inspection with the naked eye. Instruments for measuring angles were first used in the Alexandrian school, about 300 years before the Christian era.

85. Wherever we are situated on the earth we appear to be in the center of a vast sphere, on the concave surface of which all celestial objects are inscribed. If we take any two points on the surface of the sphere, as two stars for example, and imagine straight lines to be drawn to them from the eye, the angle included between these

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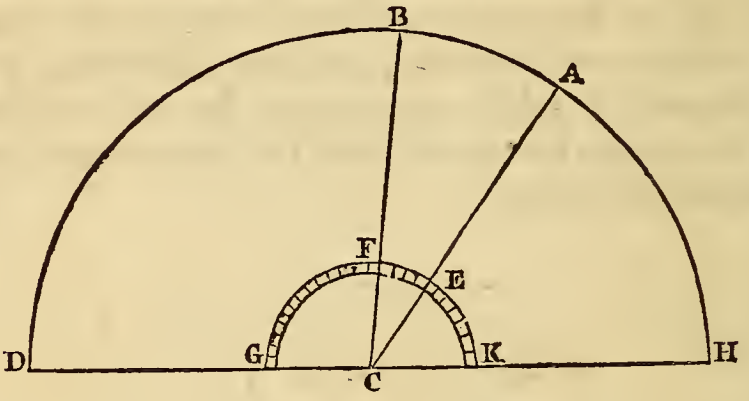
83. If the common year begins on a certain day of the week, how will it end? How is it with leap year? How does any day of the month compare in the preceding and following year with respect to the day of the week? How is this in leap year?

84. How did the most ancient nations acquire their knowledge of the heavenly bodies? When were astronomical instruments first introduced?

lines will be measured by the arc of the sky contained between the two points. Thus if HBD, (Fig. 10,) rep-

Fig. 10.



resents the concave surface of the sphere, A, B, two points on it, as two stars, and CA, CB, straight lines drawn from the spectator to those points, then the angular distance between them is measured by the arc AB, or the angle ACB. But this angle may be measured on a much smaller circle, having the same center, as EFG, since the arc EF will have the same number of degrees as the arc AB. The simplest mode of taking an angle between two stars, is by means of an arm opening at a joint like the blade of a penknife, the end of the arm moving like CE upon the graduated circle KEG.

The common surveyor's compass affords a simple example of angular measurement. Here the needle lies in a north and south line, while the circular rim of the compass, when the instrument is level, corresponds to the horizon. Hence the compass shows how many degrees any object to which we direct the eye, lies east or west of the meridian.

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85. How is the angular distance between two points on the celestial sphere measured? Explain figure 10. Show how the circles of the sphere may be truly represented by the smaller circles of the instrument, as the horizon by the surveyor's compass. Explain the simplest mode of taking angles by figure 10

86. It is obvious that the larger the graduated circle is, the more minutely its limb may be divided. If the circle is one foot in diameter, each degree will occupy $\frac{1}{10}$ of an inch. If the circle is 20 feet in diameter, a degree will occupy the space of two inches and could be easily divided to minutes, since each minute would cover a space of $\frac{1}{30}$ of an inch. Refined astronomical circles are now divided with very great skill and accuracy, the spaces between the divisions being, when read off, magnified by a microscope; but in former times, astronomers had no mode of measuring small angles but by employing very large circles. But the telescope and microscope enable us at present to measure celestial arcs much more accurately than was done by the older astronomers.

The principal instruments employed in astronomy, are the Telescope, the Transit Instrument, the Altitude and Azimuth Instrument, and the Sextant.

87. The *Telescope* has greatly enlarged our knowledge of astronomy, both by revealing to us many things invisible to the naked eye, and also by enabling us to attain a much higher degree of accuracy than we could otherwise reach, in angular measurements. It was invented by Galileo about the year 1600. The powers of the telescope were improved and enlarged by successive efforts, and finally, about 50 years ago, telescopes were constructed in England by Dr. Herschel, of a size and power that have not since been surpassed.

A complete knowledge of the telescope cannot be acquired without an acquaintance with the science of optics; but we may perhaps convey to one unacquainted with that science, some idea of the leading principles of

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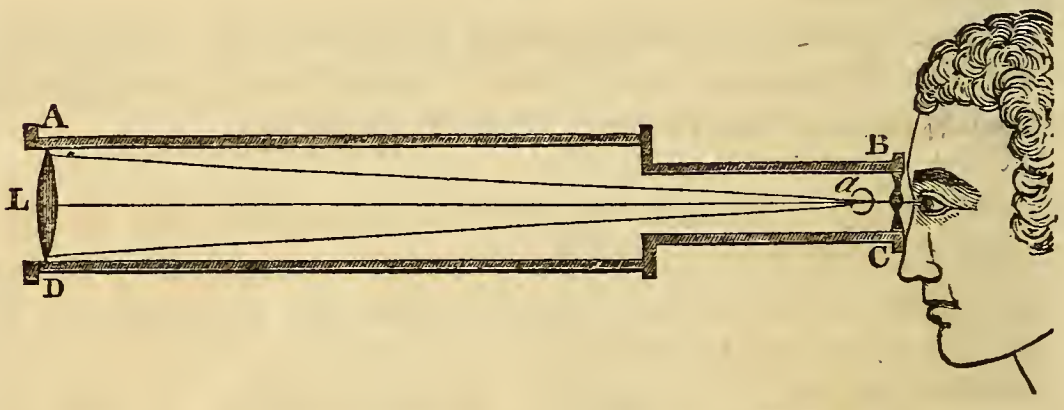
86. What is the advantage of having large circles for angular measurements? When the circle is one foot in diameter, what space will 1° occupy on the limb? What space when the circle is twenty feet in diameter? What are the principal instruments used in astronomical observations?

this noble instrument. *By means of the telescope, we first form an image of a distant object as the moon for example, and then magnify that image by a microscope.* Let us first see how the image is formed. This may be done either by a convex lens, or by a concave mirror. A convex lens is a flat piece of glass, having its two faces convex, or spherical, as is seen in a common sun glass. Every one who has seen a sun glass, knows that when held towards the sun it collects the solar rays into a small bright circle in the focus. This is in fact a small *image* of the sun. In the same manner the image of any distant object, as a star, may be formed as is represented in the following diagram. Let ABCD represent

Fig. 11.



the tube of a telescope. At the front end, or at the end which is directed towards the object, (which we will suppose to be the moon,) is inserted a convex lens, L, which receives the rays of light from the moon, and collects them into the focus at *a*, forming an image of the moon. This image is viewed by a magnifier attached to the end BC. The lens L is called the object-glass, and the microscope in BC the eye-glass. We apply a magnifier to this image just as we would to any object;

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87. Who invented the telescope? Who constructed telescopes of great size and power? Explain the leading principle of the telescope. How is the image formed? What is a convex lens? How does it affect parallel rays of light? How do we view the image formed by the lens? How is the image magnified? How is it rendered brighter?

nd by greatly enlarging its dimensions, we may render its various parts far more distinct than they would otherwise be, while at the same time the object lens collects and conveys to the eye a much greater quantity of light than would proceed directly from the body under examination. A very small beam of light only from a distant object, as a star, can enter the eye directly; but a lens one foot in diameter will collect a beam of light of the same dimensions, and convey it to the eye. By these means many obscure celestial objects become distinctly visible, which would otherwise be either too minute, or not sufficiently luminous to be seen by us.

88. But the image may also be formed by means of a concave mirror, which, as well as the convex lens, has the property of collecting the rays of light which proceed from any luminous body, and of forming an image of that body. The image formed by the concave mirror is magnified by a microscope in the same manner as when formed by the convex lens. When the lens is used to form an image, the instrument is called a *Refracting* telescope; when a concave mirror is used, it is called a *Reflecting* telescope.

The telescope in its simplest form is employed not so much for angular measurements, as for aiding the powers of vision in viewing the celestial bodies. When directed to the sun, it reveals to us various irregularities on his disk not discernible by naked vision; when turned upon the moon or the planets, it affords us new and interesting views, and enables us to see in them the lineaments of other worlds; and when brought to bear upon the fixed stars, it vastly increases their number and reveals to us many surprising facts respecting them.

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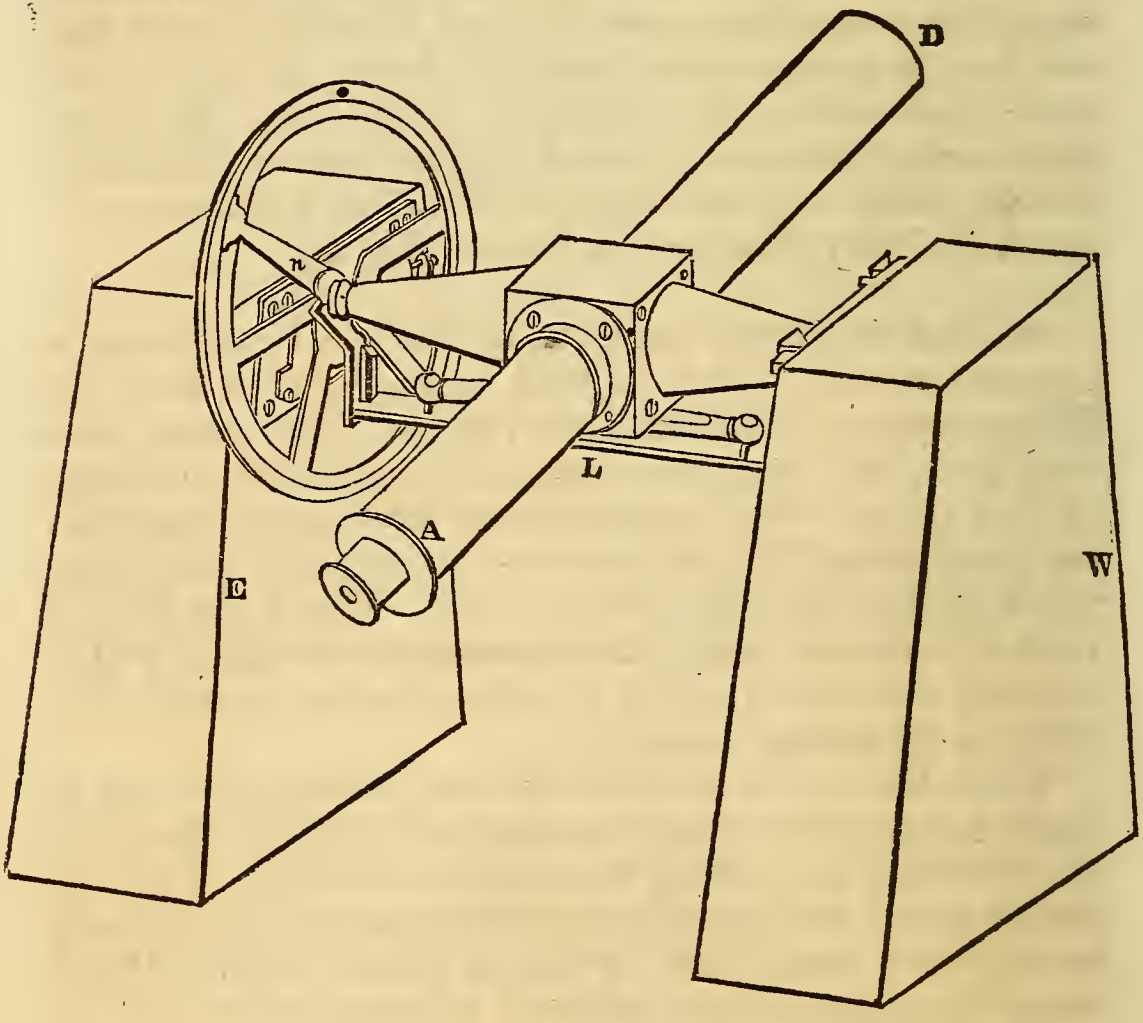
88. How is an image formed by a concave mirror? How is this image magnified? When is the instrument called a refracting and when a reflecting telescope? For what purposes are telescopes chiefly employed?

89. The *Transit Instrument* is a telescope, which is fixed permanently in the meridian, and moves only in that plane. It rests on a horizontal axis, which consists of two hollow cones applied base to base, a form uniting lightness and strength. The two ends of the axis rest

Fig. 12.



on two firm supports, as pillars of stone, for example, so connected with the building as to be as free as possible from all agitation. In figure 12, AD represents the tele-

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89. What is a Transit Instrument? On what supports does it rest as represented in figure 12. Why are they made so firm? Describe all parts of the instrument. What is its use? How used to regulate clocks and watches? What kind of time is shown when the sun is on the meridian? How is this converted into mean time? Give an example.

scope, E, W, massive stone pillars supporting the horizontal axis, beneath which is seen a spirit level, (which is used to bring the axis to a horizontal position,) and *n* a vertical circle graduated into degrees and minutes. This circle serves the purpose of placing the instrument at any required altitude, or distance from the zenith, and of course for determining altitudes and zenith distances.

The use of the transit instrument is to show the precise moment when a heavenly body is on the meridian. One of its uses is to enable us to obtain the true time, and thus to regulate our clocks and watches. We find when the sun's center is on the meridian, and this gives us the time of noon or *apparent time.* (Art. 78.) But watches and clocks usually keep *mean* time, and therefore in order to set our time piece by the transit instrument, we must apply the equation of time.

90. A *noon mark* may easily be made by the aid of the Transit Instrument. A window sill is frequently selected as a suitable place for the mark, advantage being taken of the shadow projected upon it by the perpendicular casing of the window. Let an assistant stand with a rule laid on the line of shadow and with a knife ready to make the mark, the instant when the observer at the Transit Instrument announces that the center of the sun is on the meridian. By a concerted signal, as the stroke of a bell, the inhabitants of a town may all fix a noon mark from the same observation. It must be borne in mind, however, that the noon mark gives the *apparent* time, and that the equation of time must be allowed for in setting the clock or watch. Suppose we wish to set our clock right on the first of January. We find by a table of the equation of time, that mean time then precedes apparent time 3m. 43s.; we must therefore set the clock at 3m. 43s. the instant the center of the sun is on the meridian. If the time had been the first of May instead of the first of January, then we find by the table that 3m. is to be subtracted from the apparent time, and consequently, when the center of the

90 Describe the mode of making a noon mark.

sun was on the meridian, we should set our clock at 11h. 57m. or 3m. before twelve.

91. The equation of time varies a little with different years, but the following table will always be found within a few seconds of the truth. The equation for the current year is given exactly in the American Almanac.

Equation of Time for Apparent Noon.

Days.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug	Sept.	Oct.	Nov.	D
	Add.	Add.	Add.	Add.	Sub.	Sub.	Add.	Add.	Add.	Sub.	Sub.	Sub.
	M. S.	M. S.	M. S.	M. S.	M. S.	M. S	M. S.	M. S.	M. S.	M. S.	M. S.	M. S.
1	3.43	13.53	12.42	4. 6	3. 0	2.38	3.19	6. 3	*a*0. 1	10. 9	16.15	10.54
2	4.11	14. 1	12.30	3.48	3. 7	2.29	3.31	5.59	*s*0.17	10.28	16.16	10.32
3	4.39	14. 8	12.18	3.30	3.15	2.19	3.42	5.55	0.36	10.47	16.17	10. 8
4	5. 7	14.14	12. 5	3.12	3.21	2.10	3.53	5.50	0.56	11. 6	16.17	9.45
5	5.34	14.19	11.51	2.54	3.27	2. 0	4. 4	5.45	1.15	11.24	16.16	9.20
6	6. 1	14.24	11.38	2.37	3.32	1.49	4.15	5.39	1.35	11.42	16.14	8.55
7	6.27	14.27	11.23	2.19	3.37	1.39	4.25	5.33	1.55	11.59	16.11	8.30
8	6.53	14.30	11. 8	2. 2	3.42	1.28	4.34	5.25	2.15	12.16	16. 7	8. 4
9	7.18	14.32	10.53	1.45	3.46	1.17	4.44	5.18	2.36	12.33	16. 3	7.37
10	7.43	14.33	10.38	1.28	3.49	1. 5	4.53	5. 9	2.56	12.49	15.58	7.10
11	8. 7	14.34	10.22	1.11	3.51	0.53	5. 1	5. 1	3.17	13. 5	15.51	6.43
12	8.31	14.33	10. 6	0.55	3.53	0.41	5. 9	4.51	3.38	13.20	15.44	6.15
13	8.54	14.32	9.49	0.39	3.55	0.29	5.17	4.41	3.59	13.34	15.37	5.47
14	9.16	14.30	9.32	0.23	3.56	0.17	5.24	4.31	4.20	13.49	15.28	5.18
15	9.37	14.28	9.15	0. 8	3.56	0. 4	5.30	4.20	4.41	14. 2	15.18	4.49
				Sub.		Add.						
16	9.58	14.25	8.58	0. 7	3.56	0. 8	5.37	4. 8	5. 2	14.15	15. 8	4.20
17	10.19	14.20	8.41	0.22	3.55	0.21	5.42	3.56	5.23	14.28	14.56	3.50
18	10.38	14.16	8.23	0.36	3.54	0.34	5.48	3.44	5.44	14.39	14.44	3.21
19	10.57	14.10	8. 5	0.50	3.52	0.47	5.52	3.31	6. 5	14.51	14.31	2.51
20	11.15	14. 4	7.47	1. 3	3.49	1. 0	5.57	3.17	6.26	15. 1	14.17	2.21
21	11.33	13.58	7.29	1.16	3.46	1.13	6. 0	3. 3	6.47	15.11	14. 3	1.51
22	11.49	13.50	7.11	1.29	3.42	1.26	6. 3	2.49	7. 8	15.21	13.47	1.21
23	12. 5	13.42	6.52	1.41	3.38	1.39	6. 6	2.34	7.29	15.29	13.31	0.51
24	12.20	13.34	6.34	1.52	3.33	1.52	6. 8	2.19	7.49	15.37	13.14	0.21
25	12.35	13.25	6.15	2. 4	3.28	2. 5	6. 9	2. 3	8.10	15.44	12.56	*a*0. 9
26	12.48	13.15	5.57	2.14	3.22	2.18	6.10	1.47	8.30	15.51	12.38	0.39
27	13. 1	13. 4	5.38	2.24	3.16	2.30	6.10	1.30	8.50	15.57	12.18	1. 9
28	13.13	12.54	5.20	2.34	3. 9	2.43	6.10	1.13	9.11	16. 2	11.58	1.39
29	13.24		5. 1	2.43	3. 2	2.55	6. 9	0.56	9.30	16. 6	11.38	2. 8
30	13.35		4.43	2.52	2.54	3. 8	6. 8	0.38	9.50	16.10	11.16	2.37
31	13.44		4.25		2.46		6. 5	0.20		16.13		3. 6

91. Is the equation of time the same or different in different years? In what book may it be found exactly for the current year?

92. The *Astronomical Clock* is the constant companion of the Transit Instrument. This clock is so regulated as to keep exact pace with the stars, and of course with the revolution of the earth on its axis; that is, it is regulated to sidereal time. It measures the progress of a star, indicating an hour for every 15°, and 24 hours for the whole period of the revolution of the star. Sidereal time, it will be recollected, commences when the vernal equinox is on the meridian, just as solar time commences when the sun is on the meridian. Hence, the hour by the sidereal clock has no correspondence with the hour of the day, but simply indicates how long it is since the equinoctial point crossed the meridian. For example, the clock of an observatory points to 3h 20m.; this may be in the morning, at noon, or any other time of the day, since it merely shows that it is 3h. 20m. since the equinox was on the meridian. Hence, when a star is on the meridian, the clock itself shows its right ascension; (Art. 24,) and the interval of time between the arrival of any two stars upon the meridian, is the measure of their difference of right ascension.

93. Astronomical clocks are made of the best workmanship, with a compensation pendulum, and every other advantage which can promote their regularity. The Transit Instrument itself, when once accurately placed in the meridian, affords the means of testing the correctness of the clock, since one revolution of a star from the meridian to the meridian again, ought to correspond to exactly 24 hours by the clock, and to con-

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92. How is the astronomical clock regulated? What does it measure? How many degrees does a star pass over in an hour? When does sidereal time commence? What is denoted by the hour and minute of a sidereal clock? How do we determine the right ascension of a star?

93. How is the workmanship of astronomical clocks? How is the correctness of a clock tested? To what degree of perfection are clocks brought? By what instrument are clocks regulated?

tinue the same from day to day; and the right ascension of various stars as they cross the meridian, ought to be such by the clock as they are given in the tables, where they are stated according to the accurate determinations of astronomers. Or by taking the difference of right ascension of any two stars on successive days, it will be seen whether the going of the clock is uniform for that part of the day; and by taking the right ascension of different pairs of stars, we may learn the rate of the clock at various parts of the day. We thus learn, not only whether the clock accurately measures the length of the sidereal day, but also whether it goes uniformly from hour to hour.

Although astronomical clocks have been brought to a great degree of perfection, so as to vary hardly a second for many months, yet none are absolutely perfect, and most are so far from it as to require to be corrected by means of the Transit Instrument every few days. Indeed, for the nicest observations, it is usual not to attempt to bring the clock to an absolute state of correctness, but after bringing it as near to such a state as can conveniently be done, to ascertain how much it gains or loses in a day; that is, to ascertain its *rate* of going, and to make allowance accordingly.

94. The Transit Instrument is adapted to taking observations on the meridian only; but we sometimes require to know the *altitude* of a celestial body when it is not on the meridian, and its *azimuth*, or distance from the meridian measured on the horizon. An instrument especially designed to measure altitudes and azimuths, is called an *Altitude and Azimuth Instrument*, whatever may be its particular form. When a point is on the horizon its distance from the meridian, or its azimuth, may be taken by the common surveyor's compass, the direc-

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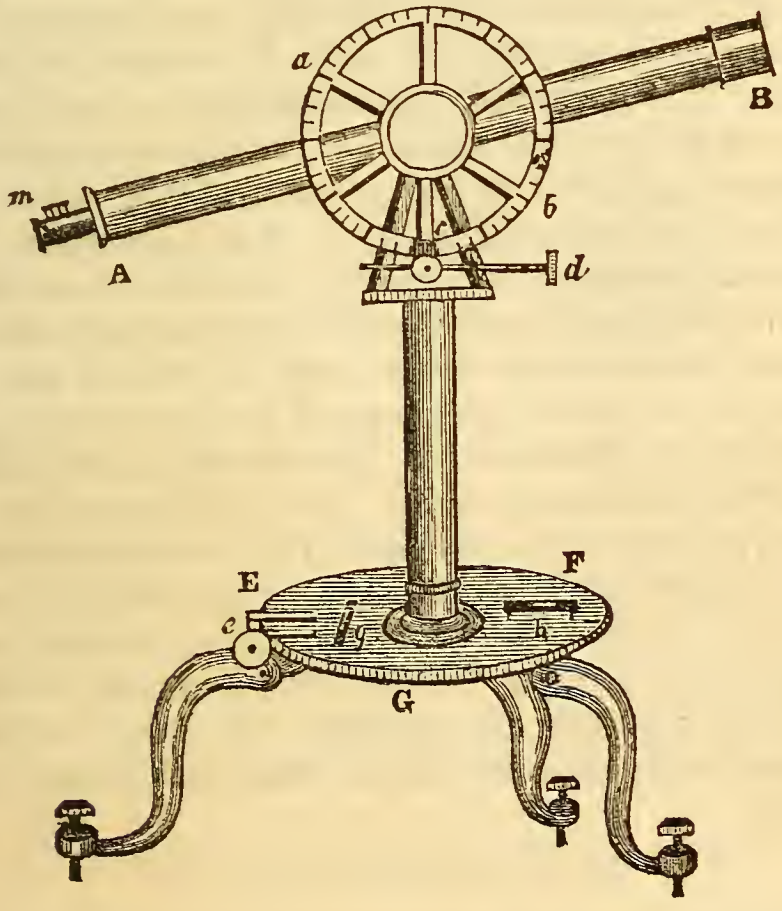
94. To what kind of observations only is the transit instrument adapted? What instrument is employed for finding altitude and azimuth? Describe the Altitude and Azimuth Instrument from figure 13

tion of the meridian being determined by the needle; but when the object, as a star, is not on the horizon, its azimuth, it must be remembered, is the arc of the horizon from the meridian to a vertical circle passing through the star; at whatever different altitudes, therefore, two stars may be, and however the plane which passes through them may be inclined to the horizon, still it is their angular distance measured *on the horizon* which determines their difference of azimuth. Figure 13 represents an Altitude and Azimuth Instrument, several of the usual appendages and subordinate contrivances being omitted for the sake of distinctness and simplicity. Here *abc* is the vertical or altitude circle, and EFG the horizontal or azimuth circle; AB is a telescope mounted on

Fig. 13.



a horizontal axis and capable of two motions, one in altitude parallel to the circle *abc*, and the other in azimuth parallel to EFG. Hence it can be easily brought to

bear upon any object. At *m*, under the eye glass of the telescope, is a small mirror placed at an angle of 45° with the axis of the telescope, by means of which the image of the object is reflected upwards, so as to be conveniently presented to the eye of the observer. At *d* is represented a *tangent screw*, by which a slow motion is given to the telescope at *c*. At *h* and *g* are seen two *spirit levels*, at right angles to each other, which show when the azimuth circle is truly horizontal. The instrument is supported on a *tripod*, for the sake of greater steadiness, each foot being furnished with a screw for levelling.

95. The SEXTANT is an instrument used for taking the angular distance between any two bodies on the surface of the celestial sphere, by reflecting the image of one of the bodies so as to coincide with the other body as seen directly. It is particularly valuable for measuring celestial arcs at sea, because it is not, like most astronomical instruments, affected by the motion of the ship.

This instrument (Fig 14,) is of a triangular shape, and is made strong and firm by metallic crossbars. It has two reflectors, I and H, called, respectively, the Index Glass, and the Horizon Glass, both of which are firmly fixed perpendicular to the plane of the instrument. The Index Glass is attached to the movable arm ID and turns as this is moved along the graduated limb EF. This arm also carries a Vernier at D, which enables us to take off minute parts of the spaces into which the limb is divided. The Horizon Glass, H, consists of two parts; the upper being transparent or open, so that the eye, looking through the telescope T, can see through it a distant body as a star at S, while the lower part is a reflector.

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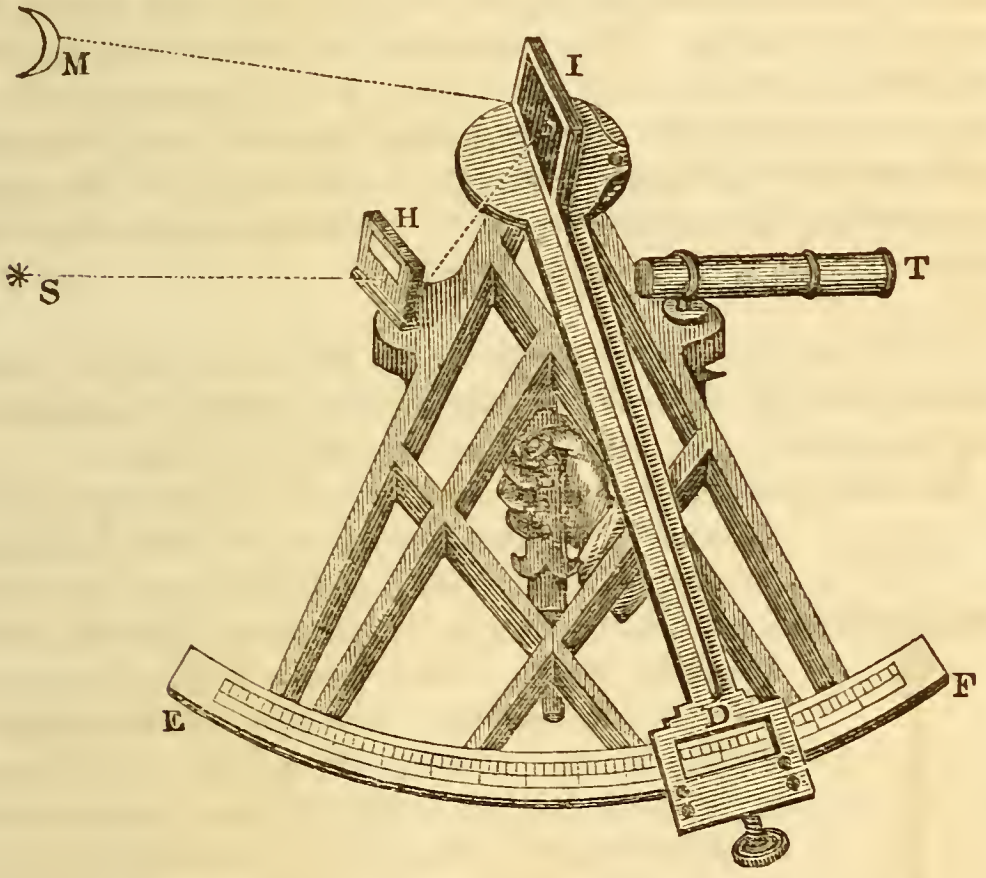
95. Define the Sextant—For what is it particularly valuable? Describe it from figure 14. Where is the Vernier and what is its use? Specify the manner in which the light comes from the object to the eye. How can we measure the angular distance between the moon and a star?

Suppose it were required to measure the angular distance between the moon and a certain star, the moon

Fig. 14.



being at M, and the star at S. The instrument is held firmly in the hand, so that the eye, looking through the telescope, sees the star S through the transparent part of the Horizon Glass. Then the movable arm ID is moved from F towards E, until the image of M is carried down to S, when the number of degrees and parts of a degree reckoned on the limb from F to the index at D, will show the angular distance between the two bodies.

FIGURE AND DENSITY OF THE EARTH.

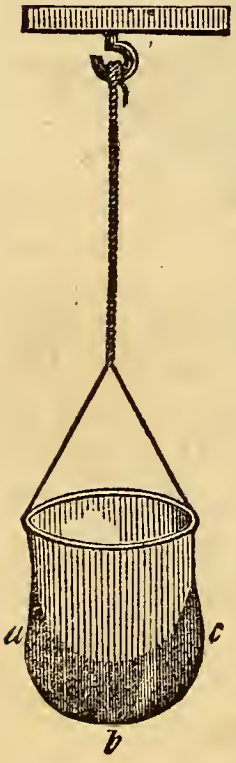
96. We have already shown, that the figure of the earth is *nearly* globular; but since the semi-diameter of the earth is taken as the base line in determining the parallax of the heavenly bodies, and lies therefore at the foundation of all astronomical measurements, it is very

important that it should be ascertained with the greatest possible exactness. Having now learned the use of astronomical instruments, and the method of measuring arcs on the celestial sphere, we are prepared to understand the methods employed to determine the exact figure of the earth. This element is indeed ascertained in different ways, each of which is independent of all the rest, namely, by investigating the effects of the *centrifugal force* arising from the revolution of the earth on its axis—by measuring *arcs of the meridian*—and by experiments with the *pendulum.*

97. First, *the known effects of the centrifugal force, would give to the earth a spheroidal figure, elevated in the equatorial, and flattened in the polar regions.*

By the centrifugal force is meant, the tendency which revolving bodies exhibit to recede from the center. Thus when a grindstone is turned swiftly, water is thrown off from it in straight lines. The same effect is noticed when a carriage wheel is driven rapidly through the water. If a pail, containing a little water, is whirled, the water rises on the sides of the pail in consequence of the centrifugal force. The same principle is more strikingly illustrated by the annexed cut, (Fig. 15,) which represents an open glass vessel suspended by a cord attached to its opposite sides, and passed through a staple in the ceiling of the room. A little water is introduced into the vessel which is made to whirl rapidly by applying the hand to the opposite sides. As it turns, the water rises on the sides of the vessel, receding as far as possible from the

Fig. 15.



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96. Why is it so necessary to ascertain accurately the semi-diameter of the earth? In how many different ways is this element ascertained? Specify them. What is meant by the centrifugal force? Give an illustration. Describe figure 15.

center. The same effect is produced by suffering the cord to untwist freely, which gives a swift revolution to the vessel. In like manner, a ball of soft clay when made to turn rapidly on its axis, swells out in the central parts and becomes flattened at the ends, forming the figure called an oblate spheroid.

Had the earth been originally constituted (as geologists suppose) of yielding materials, either fluid or semi-fluid, so that its particles could obey their mutual attraction, while the body remained at rest it would spontaneously assume the figure of a perfect sphere; as soon, however, as it began to revolve on its axis, the greater velocity of the equatorial regions would give to them a greater centrifugal force, and cause the body to swell out into the form of an oblate spheroid. Even had the solid part of the earth consisted of unyielding materials and been created a perfect sphere, still the waters that covered it would have receded from the polar and have been accumulated in the equatorial regions, leaving bare extensive regions on the one side, and ascending to a mountainous elevation on the other.

On estimating, from the known dimensions of the earth and the velocity of its rotation, the amount of the centrifugal force in different latitudes, and the figure of equilibrium which would result, Newton inferred that the earth must have the form of an oblate spheroid before the fact had been established by observation; and he assigned nearly the true ratio of the polar and equatorial diameters.

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97. What would be the figure of the earth derived from the centrifugal force? What figure would the earth have assumed if at rest? How would this figure be changed when it began to revolve? Had the earth been originally a solid sphere covered with water, how would the water have disposed itself when the earth was made to turn on its axis? How was the spheroidal figure of the earth inferred before the fact was established by observation?

98. Secondly, *the spheroidal figure of the earth is proved, by actually measuring the length of a degree on the meridian in different latitudes.*

Were the earth a perfect sphere, the section of it made by a plane passing through its center in any direction would be a perfect circle, whose curvature would be equal in all parts; but if we find by actual observation, that the curvature of the section is not uniform, we infer a corresponding departure in the earth from the figure of a perfect sphere. The task of measuring portions of the meridian, has been executed in different countries. We may know, in each case, how far we advance on the meridian, because every step we take northward, produces a corresponding increase in the altitude of the north star. That an increase of the length of the degrees of the meridian, as we advance from the equator towards the pole, really proves that the earth is flattened at the poles, will be readily seen on a little reflection. We must bear in mind that a degree is not any certain length, but only the three hundred and sixtieth part of a circle, whether great or small. If, therefore, a degree is longer in one case than in another, we infer that it is the three hundred and sixtieth part of a larger circle; and since we find that a degree towards the pole is longer than a degree towards the equator, we infer that the curvature is less in the former case than in the latter.

The result of all the measurements is, that the length of a degree increases as we proceed from the equator towards the pole, as may be seen from the following table:

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98. By what measurements is the spheroidal figure of the earth proved? What would be the curvature in all parts were the earth a perfect sphere? How may we know when we have advanced one degree northward in the meridian? Explain how an increase of the length of a degree proves that the earth is flattened towards the poles? In what places have arcs of the meridian been measured? What is the mean diameter of the earth? What is the difference between the two diameters? What fraction expresses the ellipticity of the earth?

Places of observation.	Latitude.	Length of a degree in miles
Peru,	00° 00′ 00″	68.732
Pennsylvania,	30 12 00	68.896
Italy,	43 01 00	68.998
France,	46 12 00	69.054
England,	51 29 54½	69.164
Sweden,	66 20 10	69.292

Combining the results of various estimates, the dimensions of the terrestrial spheroid are found to be as follows:

Equatorial diameter, . . .	7925.648
Polar diameter, ...	7899.170
Mean diameter, ...	7912.409

The difference between the greatest and the least, is $26.478 = \frac{1}{299}$ of the greatest. This fraction ($\frac{1}{299}$) is denominated the *ellipticity* of the earth, being the excess of the longest over the shortest diameter.

99. Thirdly, *the figure of the earth is shown to be spheroidal, by observations with the pendulum.*

If a pendulum, like that of a clock, be suspended and the number of its vibrations per hour be counted, they will be found to be different in different latitudes. A pendulum that vibrates 3600 times per hour at the equator, will vibrate $3605\frac{2}{3}$ times at London, and a still greater number of times nearer the north pole. Now the vibrations of the pendulum are produced by the force of

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96. Explain how we may ascertain the figure of the earth by means of a pendulum—How will the number of vibrations be in different latitudes? How many times will a pendulum vibrate in an hour at London, which vibrates 3600 times per hour at the equator? How are the vibrations of the pendulum produced? Why are these comparative numbers at different places measures of the relative distances from the center of the earth? What could we infer from two observations with the pendulum, one at the equator and the other at the north pole? To what conclusions have pendulum observations, made in various parts of the earth, led?

gravity. Hence their comparative number at different places is a measure of the relative forces of gravity at those places. But when we know the relative forces of gravity at different places, we know their relative distances from the center of the earth, because the nearer a place is to the center of the earth, the greater is the force of gravity. Suppose, for example, we should count the number of vibrations of a pendulum at the equator, and then carry it to the north pole and count the number of vibrations made there in the same time; we should be able from these two observations to estimate the relative forces of gravity at these two points; and having the relative forces of gravity, we can thence deduce their relative distances from the center of the earth, and thus obtain the polar and equatorial diameters. Observations of this kind have been taken with the greatest accuracy in many places on the surface of the earth, at various distances from each other, and they lead to the same conclusions respecting the figure of the earth, as those derived from measuring arcs of the meridian.

100. The *density* of the earth compared with water, that is, its specific gravity, is $5\frac{1}{2}$. The density was first estimated by Dr. Hutton, from observations made by Dr. Maskelyne, Astronomer Royal, on Schehallien, a mountain of Scotland, in the year 1774. Thus, let M (Fig. 16,) represent the mountain, D, B, two stations on opposite sides of the mountain, and I a star; and let IE and IG be the zenith distances as determined by the difference of latitude of the two stations. But the apparent zenith distances as determined by the plumb line are IE′ and IG′. The deviation towards the mountain on each side exceeded 7″. The attraction of the mountain being observed on both sides of it, and its mass being computed from a number of sections taken in all di

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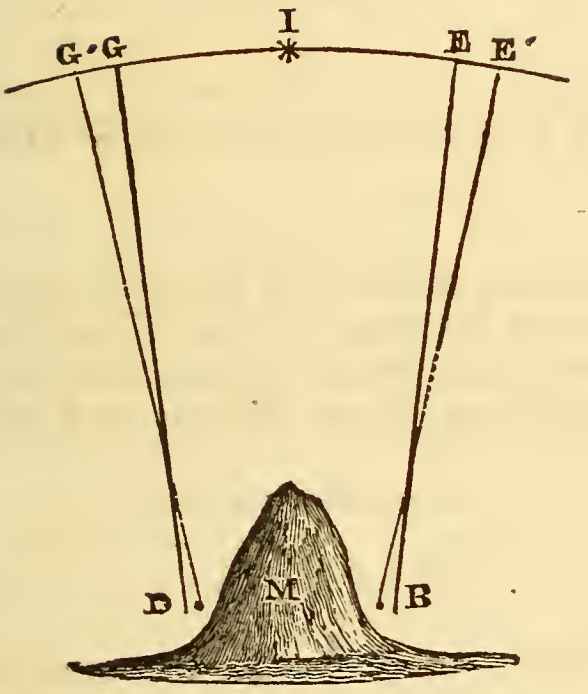
100 What is the specific gravity of the earth? How was it ascertained? Explain figure 16. Why is the density of the earth so important an element?

Fig. 16.



rections, these data, when compared with the known attraction and magnitude of the earth, led to a knowledge of its mean density. According to Dr. Hutton, this is to that of water as 9 to 2; but later and more accurate estimates have made the specific gravity of the earth as stated above. But this density is nearly double the average density of the materials that compose the exterior crust of the earth, showing a great increase of density towards the center.

The density of the earth is an important element, as we shall find that it helps us to a knowledge of the density of each of the other members of the solar system.

PART II.—OF THE SOLAR SYSTEM.

101. Having considered the Earth, in its astronomical relations, and the Doctrine of the Sphere, we proceed now to a survey of the Solar System, and shall treat successively of the Sun, Moon, Planets, and Comets.

CHAPTER I.

OF THE SUN—SOLAR SPOTS—ZODIACAL LIGHT.

102. The *figure* which the sun presents to us is that of a perfect circle, whereas most of the planets exhibit a disk more or less elliptical, indicating that the true shape of the body is an oblate spheroid. So great, however, is the distance of the sun, that a line 400 miles long would subtend an angle of only 1″ at the eye, and would therefore be the least space that could be measured. Hence, were the difference between two conjugate diameters of the sun any quantity less than this, we could not determine by actual measurement that it existed at all. Still we learn from theoretical considerations, founded upon the known effects of centrifugal force, arising from the sun's revolution on his axis, that his figure is not a perfect sphere, but is slightly spheroidal.

103. The *distance of the sun from the earth*, is nearly 95,000,000 miles. In order to form some faint concep-

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101. What subjects are treated of in Part II

102. What figure does the sun present to us? What angle would a line of 400 miles on the sun's disk subtend? How is it inferred that the figure of the sun is spheroidal?

tion at least of this vast distance, let us reflect that a railway car, moving at the rate of 20 miles per hour, would require more than 500 years to reach the sun.

The apparent *diameter* of the sun is a little more than half a degree, (32′ 3″.) Its linear diameter is about 885,000 miles; and since the diameter of the earth is only 7912 miles, the latter number is contained in the former nearly 112 times; so that it would require one hundred and twelve bodies like the earth, if laid side by side, to reach across the diameter of the sun; and a ship sailing at the rate of ten miles an hour, would require more than ten years to sail across the solar disk.

The sun is about 1,400,000 times as large as the earth. The distance of the moon from the earth being 238,000 miles, were the center of the sun made to coincide with the center of the earth, the sun would extend every way from the earth nearly twice as far as the moon.

104. In *density*, the sun is only one-fourth that of the earth, being but a little heavier than water; and the quantity of matter in the sun is three hundred and fifty thousand times as great as in the earth. A body would weigh nearly 28 times as much at the sun as at the earth. A man weighing 200 lbs. would, if transported to the surface of the sun, weigh 5,580 lbs., or nearly $2\frac{1}{2}$ tons. To lift one's limb, would, in such a case, be beyond the ordinary power of the muscles. At the surface of the earth, a body falls through $16\frac{1}{12}$ feet in a second;

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103. What is the distance of the sun from the earth? How long would a railway car, moving at the rate of 20 miles per hour, require to reach the sun? How many bodies equal to the earth could lie side by side across the sun? How long would a ship be in sailing across it at 10 miles an hour? If the sun's center were made to coincide with the center of the earth, how much farther would it reach than the moon? What is the sun's apparent diameter? What is its linear diameter?

104. In density how does the sun compare with the earth? How in quantity of matter? How much more would a body weigh at the sun than at the earth? How far would a body fall in one second at the surface of the sun?

but a body would fall at the sun in one second through 448.7 feet.

SOLAR SPOTS.

105. The surface of the sun, when viewed with a telescope, usually exhibits dark spots, which vary much, at different times, in number, figure, and extent. One hundred or more, assembled in several distinct groups, are sometimes visible at once on the solar disk. The greatest part of the solar spots are commonly very small, but occasionally a spot of enormous size is seen occupying an extent of 50,000 miles in diameter. They are sometimes even visible to the naked eye, when the sun is viewed through colored glass, or, when near the horizon, it is seen through light clouds or vapours. When it is recollected that 1″ of the solar disk implies an extent of 400 miles, it is evident that a space large enough to be seen by the naked eye, must cover a very large extent.

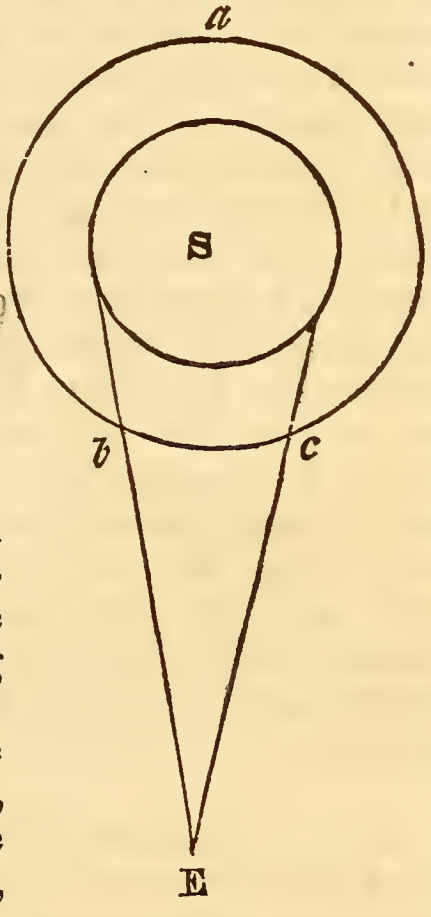
A solar spot usually consists of two parts, the *nucleus* and the *umbra*, (Fig. 17.) The nucleus is black, of a

Fig. 17.

105. *Solar spots.*—Are they constant or variable in number and appearance? How many are sometimes seen on the sun's disk at once? Are they usually large or small? How many miles in diameter are the largest? Describe a spot. What changes occur in the nucleus? What is the umbra? In what part of the sun do the spots mostly appear? What apparent motions have they? What is the period of their revolution?

very irregular shape, and is subject to great and sudden changes, both in form and size. Spots have sometimes seemed to burst asunder, and to project fragments in different directions. The umbra is a wide margin of lighter shade, and is often of greater extent than the nucleus. The spots are usually confined to a zone extending across the central regions of the sun, not exceeding 60° in breadth. When the spots are observed from day to day, they are seen *to move across the disk of the sun*, occupying about two weeks in passing from one limb to the other. After an absence of about the same period, the spot returns, having taken 27d. 7h. 37m. in the entire revolution.

Fig. 18



106. The spots must be nearly or quite in *contact with the body of the sun.* Were they at any considerable distance from it, the time during which they would be seen on the solar disk, would be less than that occupied in the remainder of the revolution. Thus, let S, (Fig. 18,) be the sun, E the earth, and *abc* the path of the body, revolving about the sun. Unless the spot were nearly or quite in contact with the body of the sun, being projected upon his disk only while passing from *b* to *c*, and being invisible while describing the arc *cab*, it would of course be out of sight longer than in sight, whereas the two periods are found to be equal. Moreover,

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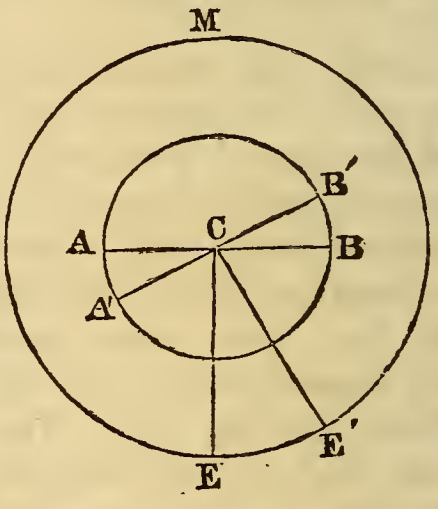
106. How are the spots known to be nearly or quite in contact with the body of the sun? Illustrate by figure 18. What causes the motion of the spots? What is the period of the sun's revolution on his axis? Explain by figure 19.

the lines which all the solar spots describe on the disk of the sun, are found to be parallel to each other, like the circles of diurnal revolution around the earth, and hence it is inferred that they arise from a similar cause, namely, *the revolution of the sun on its axis*, a fact which is thus made known to us.

But although the spots occupy about $27\frac{1}{4}$ days in passing from one limb of the sun around to the same limb again, yet this is not the period of the sun's revolution on his axis, but exceeds it by nearly two days. For, let AA′B (Fig. 19,) represent the sun, and EE′M the orbit of the earth. Thus, when the earth is at E, the visible disk of the sun will be AA′B; and if the earth remained stationary at E, the time occupied by a spot after leaving A until it returned to A, would be just equal to the time of the sun's revolution on his axis. But during the $27\frac{1}{4}$ days in which the spot has been performing its apparent revolution, the earth has been advancing in his orbit from E to E′, where the visible disk of the sun is A′B′. Consequently, before the spot can appear again on the limb from which it set out, it must describe so much more than an entire revolution as equals the arc AA′, and this occupies nearly two days, which subtracted from $27\frac{1}{4}$ days, makes the sun's revolution on its axis about $25\frac{1}{2}$ days; or more accurately, it is 25d. 9h. 56m.

Fig. 19.



107. A telescope of moderate powers is sufficient to show the spots on the sun, and it is earnestly recommended to the learner to avail himself of the first oppor-

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107. How large a telescope is sufficient to view the spots on the sun? How is the eye protected from the glare of the sun's light? How may these shades be made?

tunity he may have, to view them for himself. For observations on the sun, telescopes are usually furnished with colored glass shades, which are screwed upon the end of the instrument to which the eye is applied, for the purpose of protecting the eye from the glare of the sun's light. Such screens may be easily made by holding a small piece of window glass over the flame of a lamp, the wick being raised higher than usual so as to smoke freely.

108. The *cause* of the solar spots is unknown. It is not easy to determine what it is that occasions such changes on the surface of the sun; but various conjectures have been proposed by different astronomers. Galileo supposed that the dark part of a spot is owing to black cinders which rise from the interior of the sun, where they are formed by the action of heat, constituting a kind of volcanic lava that floats upon the surface of the fiery flood, which he supposed to constitute the outer portion of the sun. But the vast extent which these spots occasionally assume is unfavourable to such a supposition. It is incredible that a quantity of volcanic lava should suddenly rise to the surface of the sun, sufficient to occupy (as a spot is sometimes found to do) 2000,000,000 square miles.

Dr. Herschel proposed a theory respecting the nature and constitution of the sun, which, more from respect to his authority than on account of any evidence by which it is supported, has been generally received. According to him, the sun is itself an opake body like the earth, but is enveloped at a considerable distance from his body by two different strata of clouds, the exterior

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108. Is the cause of solar spots well known? What was Galileo's hypothesis? What objections are there against it? What is Herschel's theory of the nature and constitution of the sun? What sort of a body does he consider the sun itself? By what is it encompassed? Where is the repository of the sun's light and heat? How does he explain the spots? What objections are there to this theory? What are *faculæ?*

stratum being the fountain from which emanates the sun's light and heat. The solar spots arise from the occasional displacement of portions of this envelope of clouds, disclosing to view tracts of the solid body of the sun.

We regard this view of the origin of the sun's light and heat as unsubstantiated by any satisfactory proofs, and as in itself highly improbable. Such a medium would be a very unsuitable repository for the intense heat of the sun, which can arise only from fixed matter in a state of high ignition. The most probable supposition is, that the surface of the sun consists of melted matter in such a state. We must confess our ignorance of any known cause which is adequate to explain the sudden extinction and removal of so large portions of this fiery flood, as is occupied by some of the solar spots.

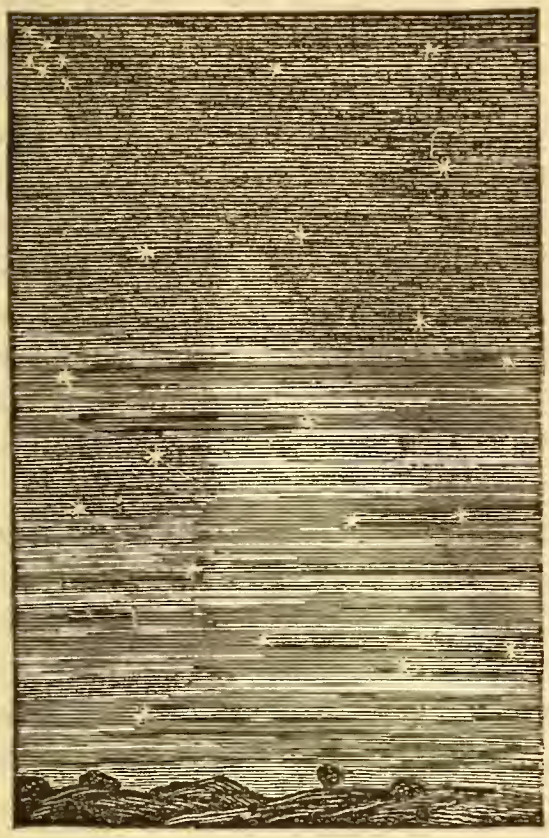
Besides the dark spots on the sun, there are also seen, in different parts, places that are brighter than the neighboring portions of the disk. These are called *faculæ*. Other inequalities are observable in powerful telescopes, all indicating that the surface of the sun is in a state of constant and powerful agitation.

ZODIACAL LIGHT.

109. The Zodiacal Light is a faint light resembling the tail of a comet, and is seen at certain seasons of the year following the course of the sun after evening twilight, or preceding his approach in the morning sky. Figure 20 represents its appearance as seen in the evening in March, 1836. The following are the leading facts respecting it.

1. *Its form is that of a luminous pyramid*, having its base towards the sun. It reaches to an immense distance from the sun, sometimes even beyond the orbit of the earth. It is brighter in the parts nearer the sun than in those that are more remote, and terminates in an obtuse apex, its light fading away by insensible gradations, until it becomes too feeble for distinct vision. Hence its limits are at the same time fixed at different dis-

Fig. 20.



tances from the sun by different observers, according to their respective powers of vision.

2. *Its aspects vary very much with the different seasons of the year.* About the first of October, in our climate (Lat. 41° 18′) it becomes visible before the dawn of day, rising along north of the ecliptic, and terminating above the nebula of Cancer. About the middle of November, its vertex is in the constellation Leo. At this time no traces of it are seen in the west after sunset, but about the first of December it becomes faintly visible in the west, crossing the Milky Way near the horizon, and reaching from the sun to the head of Capricornus, forming, as its brightness increases, a counterpart to the Milky

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109. *Zodiacal Light.*—Describe it. When and where seen? What is its form? How far does it reach? Where brightest? How do its aspects vary at different seasons of the year? What motions has it? Is it equally conspicuous every year? What was it formerly held to be? With what phenomenon has it been supposed to be connected?

Way, between which on the right, and the Zodiacal Light on the left, lies a triangular space embracing the Dolphin. Through the month of December, the Zodiacal Light is seen on both sides of the sun, namely, before the morning and after the evening twilight, sometimes extending 50° westward, and 70° eastward of the sun at the same time. After it begins to appear in the western sky, it increases rapidly from night to night, both in length and brightness, and withdraws itself from the morning sky, where it is scarcely seen after the month of December, until the next October.

3. *The Zodiacal Light moves through the heavens in the order of the signs.* It moves with unequal velocity, being sometimes stationary and sometimes retrogade, while at other times it advances much faster than the sun. In February and March, it is very conspicuous in the west, reaching to the Pleiades and beyond; but in April it becomes more faint, and nearly or quite disappears during the month of May. It is scarcely seen in this latitude during the summer months.

4. *It is remarkably conspicuous at certain periods of a few years, and then for a long interval almost disappears.*

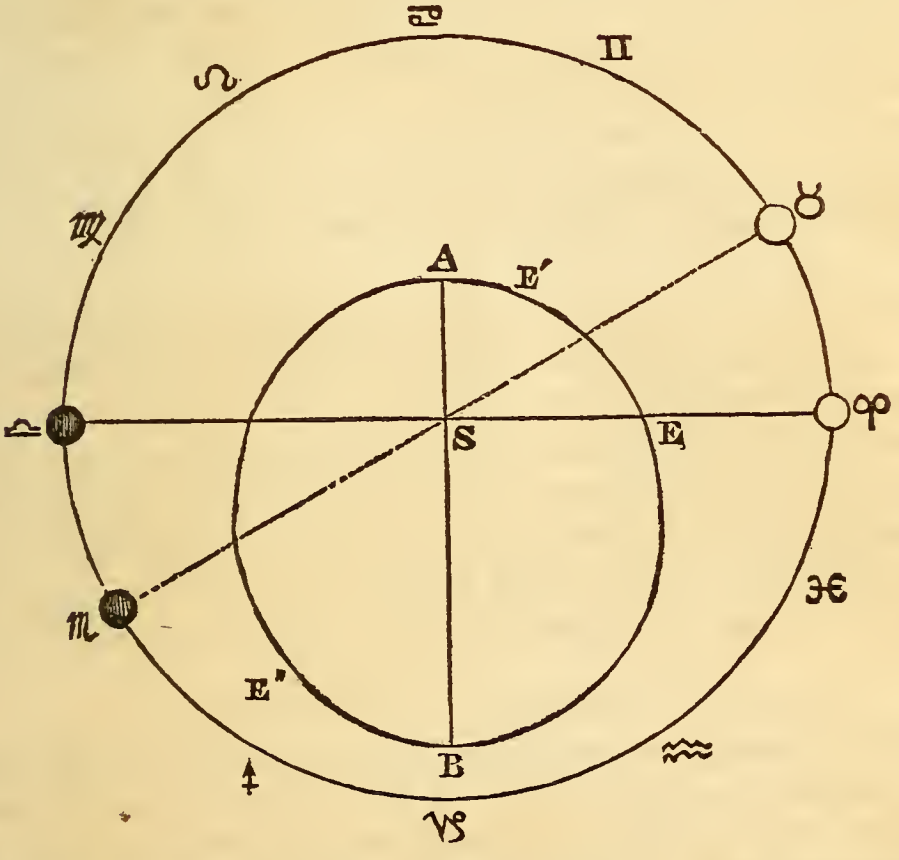
5. *The Zodiacal Light was formerly held to be the atmosphere of the sun.* But La Place has shown that the solar atmosphere could never reach so far from the sun as this light is seen to extend. It has been supposed by others to be a nebulous body revolving around the sun. The author of this work has ventured to suggest the idea, that the extraordinary *Meteoric Showers*, which at different periods visit the earth, especially in the month of November, may be derived from this body. *See American Journal of Science, Vol. 29, p. 378.*

CHAPTER II.

OF THE APPARENT ANNUAL MOTION OF THE SUN—SEASONS —FIGURE OF THE EARTH'S ORBIT.

110. The revolution of the earth around the sun once a year, produces an apparent motion of the sun around the earth in the same period. When bodies are at such a distance from each other as the earth and the sun, a spectator on either would project the other body upon the concave sphere of the heavens, always seeing it on the opposite side of a great circle, 180° from himself. Thus when the earth arrives at Libra (Fig. 21,) we see

Fig. 21.



the sun in the opposite sign Aries. When the earth moves from Libra to Scorpio, as we are unconscious of our own motion, the sun it is that appears to move from Aries to Taurus, being always seen in the heavens, where

a line drawn from the eye of the spectator through the body meets the concave sphere of the heavens. Hence the line of projection carries the sun forward on one side of the ecliptic, at the same rate as the earth moves on the opposite side; and therefore, although we are unconscious of our own motion, we can read it from day to day in the motions of the sun. If we could see the stars at the same time with the sun, we could actually observe from day to day the sun's progress through them, as we observe the progress of the moon at night; only the sun's rate of motion would be nearly fourteen times slower than that of the moon. Although we do not see the stars when the sun is present, yet after the sun is set, we can observe that it makes daily progress eastward, as is apparent from the constellations of the Zodiac occupying, successively, the western sky after sunset, proving that either all the stars have a common motion eastward independent of their diurnal motion, or that the sun has a motion past them, from west to east. We shall see hereafter abundant evidence to prove, that this change in the relative position of the sun and stars, is owing to a change in the apparent place of the sun, and not to any change in the stars.

111. Although the apparent revolution of the sun is in a direction opposite to the real motion of the earth, as regards absolute space, yet both are nevertheless from west to east, since these terms do not refer to any directions in absolute space, but to the order in which certain constellations (the constellations of the Zodiac) succeed one another. The earth itself, on opposite sides of its orbit, does in fact move towards directly opposite points

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110. What produces the apparent motion of the sun around the earth once a year? How would a spectator on either body see the other? When the earth is at Libra, where does the sun appear to be? Explain figure 21. If the stars were visible in the day time, how could we determine the sun's path? What change do the constellations of the Zodiac undergo with respect to the sun?

of space; but it is all the while pursuing its course in the order of the signs. In the same manner, although the earth turns on its axis from west to east, yet any place on the surface of the earth is moving in a direction in space exactly opposite to its direction twelve hours before. If the sun left a visible trace on the face of the sky, the ecliptic would of course be distinctly marked on the celestial sphere as it is on an artificial globe; and were the equator delineated in a similar manner, (by any method like that supposed in Art. 33,) we should then see at a glance the relative position of these two circles, the points where they intersect one another constituting the equinoxes, the points where they are at the greatest distance asunder, or the solstices, and various other particulars, which for want of such visible traces, we are now obliged to search for by indirect and circuitous methods. It will even aid the learner to have constantly before his mental vision, an imaginary delineation of these two important circles on the face of the sky.

112. *The equator makes an angle with the ecliptic of* 23° 28′. This is called the obliquity of the ecliptic. As the sun and earth are both always in the ecliptic, and as the motion of the earth in one part of it makes the sun appear to move in the opposite part at the same rate, the sun apparently descends in the winter 23° 28′ to the south of the equator, and ascends in the summer the same number of degrees to the north of it. We must keep in mind that the celestial equator and the celestial ecliptic are here understood, and we may imagine them

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111. In what sense are the motions of the sun and earth opposite, and in what sense in the same direction? If the ecliptic and equator were distinctly delineated on the face of the sky, what points in them could be easily observed?

112. What angle does the equator make with the ecliptic? In what circle do the sun and earth always appear? How far do they recede from the equator? How does the obliquity of the ecliptic vary?

to be two great circles distinctly delineated on the face of the sky. On comparing observations made at different periods for more than two thousand years, it is found, that the obliquity of the ecliptic is not constant, but that it undergoes a slight diminution from age to age, amounting to 52″ in a century, or about half a second annually. We might apprehend that by successive approaches to each other the equator and ecliptic would finally coincide; but astronomers have found by a most profound investigation, founded on the principles of universal gravitation, that this variation is confined within certain narrow limits, and that the obliquity, after diminishing for some thousands of years, will then increase for a similar period, and will thus vibrate for ever about a mean value.

113. Let us conceive of the sun as at that point of the ecliptic where it crosses the equator, that is, at one of the equinoxes, as the vernal equinox. Suppose he stands still then for twenty four hours. The revolution of the earth on its axis from east to west during this twenty four hours, will make the sun appear to describe a great circle from east to west, coinciding with the equator. At the end of this period, suppose the sun to move northward one degree and to remain there for the next twenty-four hours, in which time the revolution of the earth will make the sun appear to describe another circle from east to west, parallel to the equator, but one degree north of it. Thus we may conceive of the sun as moving one degree every day for about three months, when it will reach the point of the ecliptic farthest from the equator, which is called the *tropic* from a Greek

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113. Suppose the sun to start from the equator and to advance one degree north daily, explain its apparent diurnal revolutions. When is the sun at the northern tropic? When is he at the southern tropic? How are the respective meridian altitudes of the sun at these periods? How do we find from these observations, the obliquity of the ecliptic?

word (τρεπω) which signifies to turn, because when the sun arrives at this point, his motion in his orbit carries him continually towards the equator, and therefore he seems to turn about.

When the sun is at the northern tropic, which happens about the 21st of June, his elevation above the southern horizon at noon, is the greatest of the year; and when he is at the southern tropic, about the 21st of December, his elevation at noon is the least in the year. The difference between these two meridian altitudes, will give the whole distance from one tropic to the other, and consequently twice the distance from each tropic to the equator. By this means we find how far the tropic is from the equator, and that gives us the inclination of the two circles to one another; for the greatest distance between any two great circles on the sphere, is always equal to the angle which they make with each other.

114. *The dimensions of the earth's orbit, when compared with its own magnitude, are immense.*

Since the distance of the earth from the sun is 95,000,000 miles, and the length of the entire orbit nearly 600,000,000 miles, it will be found, on calculation, that the earth moves 1,640,000 miles per day, 68,000 miles per hour, 1,100 miles per minute, and nearly 19 miles every second, a velocity nearly sixty times as great as the maximum velocity of a cannon ball. A place on the earth's equator turns, in the diurnal revolution, at the rate of about 1,000 miles an hour and $\frac{5}{18}$ of a mile per second. The motion around the sun, therefore, is nearly seventy times as swift as the greatest motion around the axis.

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114. What is said of the dimensions of the earth's orbit? At what rate does the earth move in its orbit per day, hour, minute, and second? How far does a place on the earth's equator move per hour and second? How much swifter is the motion in the orbit than on its axis?

THE SEASONS.

115. *The change of seasons depends on two causes,* (1) *the obliquity of the ecliptic, and* (2) *the earth's axis always remaining parallel to itself.* Had the earth's axis been perpendicular to the plane of its orbit, the equator would have coincided with the ecliptic, and the sun would have constantly appeared in the equator. To the inhabitants of the equatorial regions, the sun would always have appeared to move in the prime vertical; and to the inhabitants of either pole, he would always have been in the horizon. But the axis being turned out of a perpendicular direction 23° 28′, the equator is turned the same distance out of the ecliptic; and since the equator and ecliptic are two great circles which cut each other in two opposite points, the sun, while performing his circuit in the ecliptic, must evidently be once a year in each of those points, and must depart from the equator of the heavens to a distance on either side equal to the inclination of the two circles, that is, 23° 28′.

116. The earth being a globe, the sun constantly enlightens the half next to him,* while the other half is in darkness. The boundary between the enlightened and unenlightened part, is called *the circle of illumination.* When the earth is at one of the equinoxes, the sun is at the other, and the circle of illumination passes through both the poles. When the earth reaches one of the

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115. The *Seasons.*—On what two causes does the change of seasons depend? Had the earth's axis been perpendicular to the plane of its orbit, in what great circle would the sun always have appeared to move?

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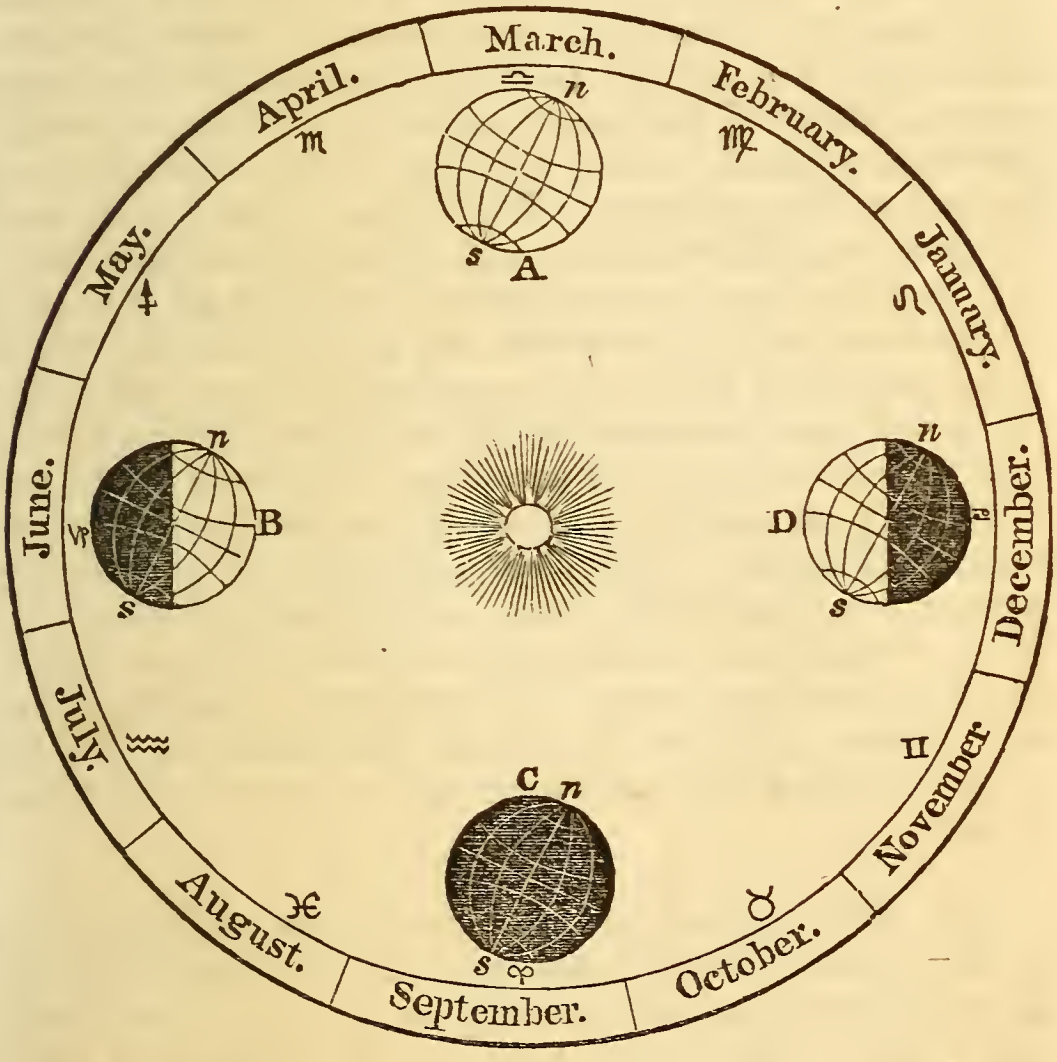
* In fact, the sun enlightens a little more than half the earth, since on account of his vast magnitude the tangents drawn from opposite sides of the sun to opposite sides of the earth, converge to a point behind the earth, as will be seen by and by in the representation of eclipses.

tropics, the sun being at the other, the circle of illumination cuts the earth, so as to pass 23° 28′ beyond the nearer, and the same distance short of the remoter pole. These results would not be uniform, were not the earth's axis always to remain parallel to itself. The following figure will illustrate the foregoing statements.

Fig. 22.



Let ABCD represent the earth's place in different parts of its orbit, having the sun in the center. Let A,

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116. How much of the earth does the sun enlighten at once? Define the circle of illumination. How does it cut the earth at the equinoxes? How at the solstices? Explain figure 22. When the earth is at one of the tropics and the sun at the other, where is it continual day and where continual night?

C, be the positions of the earth at the equinoxes, and B, D, its positions at the tropics, the axis *ns* being always parallel to itself.* At A and C the sun shines on both *n* and *s*; and now let the globe be turned round on its axis, and the learner will easily conceive that the sun will appear to describe the equator, which being bisected by the horizon of every place, of course the day and night will be equal in all parts of the globe.† Again, at B when the earth is at the southern tropic, the sun shines $23\frac{1}{2}°$ beyond the north pole *n*, and falls the same distance short of the south pole *s*. The case is exactly reversed when the earth is at the northern tropic and the sun at the southern. While the earth is at one of the tropics, at B for example, let us conceive of it as turning on its axis, and we shall readily see that all that part of the earth which lies within the north polar circle will enjoy continual day, while that within the south polar circle will have continual night, and that all other places will have their days longer as they are nearer to the enlightened pole, and shorter as they are nearer to the unenlightened pole. This figure likewise shows the successive positions of the earth at different periods of the year, with respect to the signs, and what months correspond to particular signs. Thus the earth enters Libra and the sun Aries on the 21st of March, and on the 21st of June the earth is just entering Capricorn and the sun Cancer.

117. Had the axis of the earth been perpendicular to the plane of the ecliptic, then the sun would always have appeared to move in the equator, the days would every where have been equal to the nights, and there could have been no change of seasons. On the other hand, had the inclination of the ecliptic to the equator

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* The learner will remark that the hemisphere towards *n* is above, and that towards *s* is below the plane of the paper. It is important to form a just conception of the position of the axis with respect to the plane of its orbit.

† At the pole, the solar disk, at the time of the equinox, appears bisected by the horizon.

been much greater than it is, the vicissitudes of the seasons would have been proportionally greater than at present. Suppose, for instance, the equator had been at right angles to the ecliptic, in which case the poles of the earth would have been situated in the ecliptic itself; then in different parts of the earth the appearances would have been as follows. To a spectator on the equator, the sun as he left the vernal equinox would every day perform his diurnal revolution in a smaller and smaller circle, until he reached the north pole, when he would halt for a moment, and then wheel about and return to the equator in the reverse order. The progress of the sun through the southern signs, to the south pole, would be similar to that already described. Such would be the appearances to an inhabitant of the equatorial regions. To a spectator living in an oblique sphere, in our own latitude for example, the sun while north of the equator would advance continually northward, making his diurnal circuits in parallels farther and farther distant from the equator, until he reached the circle of perpetual apparition, after which he would climb by a spiral course to the north star, and then as rapidly return to the equator. By a similar progress southward, the sun would at length pass the circle of perpetual occultation, and for some time (which would be longer or shorter according to the latitude of the place of observation) there would be continual night.

The great vicissitudes of heat and cold which would attend such a motion of the sun, would be wholly incompatible with the existence of either the animal or the vegetable kingdoms, and all terrestrial nature would

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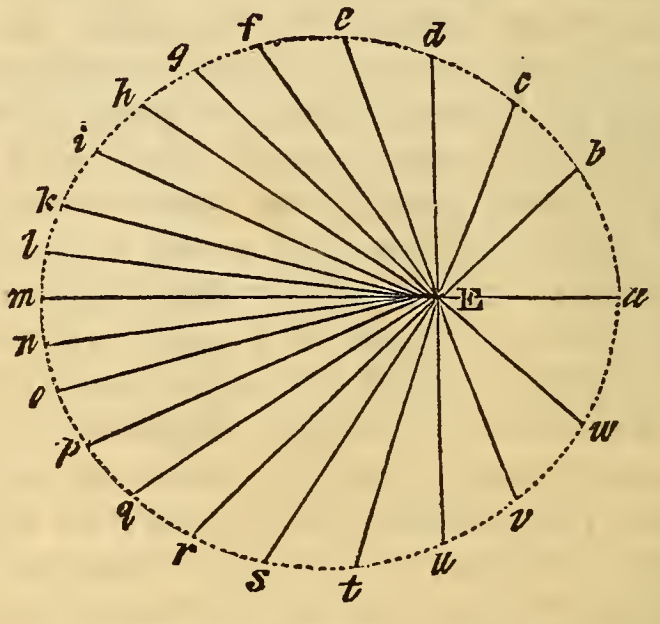
117. Had the earth's axis been perpendicular to the plane of the ecliptic, would there have been any change of seasons? What would have been the consequence had the equator been at right angles to the ecliptic? How would the sun appear to move to a person on the equator? How to one situated at the pole? How to an inhabitant of an oblique sphere? How would have been the vicissitudes of heat and cold?

be doomed to perpetual sterility and desolation. The happy provision which the Creator has made against such extreme vicissitudes, by confining the changes of the seasons within such narrow bounds, conspires with many other express arrangements in the economy of nature to secure the safety and comfort of the human race.

FIGURE OF THE EARTH'S ORBIT.

118. Thus far we have taken the earth's orbit as a great circle, such being the projection of it on the celestial sphere ; but we now proceed to investigate its actual figure.

Fig. 23.



Were the earth's path a circle, having the sun in the center, the sun would always appear to be at the same

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118. Were the earth's path a circle, how would the distance of the sun from us always appear ? Define the radius vector. What do we infer from the fact that the radius vector is constantly varying ? How do we learn the relative distances of the earth ? How do we construct a figure representing the earth's orbit ? Explain figure 23.

distance from us; that is, the radius of its orbit, or *radius vector*, the name given to a line drawn from the center of the sun to the orbit of any planet, would always be of the same length. But the earth's distance from the sun is constantly varying, which shows that its orbit is not a circle. We learn the true figure of the orbit, by ascertaining the *relative distances* of the earth from the sun at various periods of the year. These all being laid down in a diagram, according to their respective lengths, the extremities, on being connected, give us our first idea of the shape of the orbit, which appears of an oval form, and at least *resembles* an ellipse; and, on further trial, we find that it has the properties of an ellipse. Thus, let E (Fig. 23,) be the place of the earth, and *a*, *b*, *c*, &c. successive positions of the sun; the *relative* lengths of the lines E*a*, E*b*, &c. being known: on connecting the points, *a*, *b*, *c*, &c. the resulting figure indicates the true shape of the earth's orbit.

119. These relative distances are found in two different ways; first, *by changes in the sun's apparent diameter*, and, secondly, *by variations in his angular velocity*. The same object appears to us smaller in proportion as it is more distant; and if we see a heavenly body varying in size at different times, we infer that it is at different distances from us; that when largest, it is nearest to us, and when smallest, farthest off. Now when the sun's diameter is measured accurately by instruments, it is found to vary from day to day, being when greatest more than thirty-two minutes and a half, and when smallest only thirty-one minutes and a half, differing in all, about seventy-five seconds. When the diameter is greatest, which happens in January, we know

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119. How does the same body appear when at different distances? What inferences do we make from its variations of size? How much does the apparent diameter of the sun vary in different parts of the year? When is it greatest, and when smallest? Define the terms perihelion and aphelion.

that the sun is nearest to us; and when the diameter is least, which occurs in July, we infer that the sun is at the greatest distance from us.

The point where the earth or any planet, in its revolution, is nearest the sun, is called its *perihelion;* the point where it is farthest from the sun, its *aphelion.*

120. Similar conclusions may be drawn from observations on the sun's *angular velocity.* A body appears to move most rapidly when nearest to us. Indeed the apparent velocity of the sun increases rapidly as it approaches us, and as rapidly diminishes when it recedes from us. If it were to come twice as near as before it would appear, to move not merely twice as swift, but four times as swift; if it came ten times nearer, its apparent velocity would be one hundred times as great as before. We say, therefore, that the velocity varies inversely as the square of the distance, for as the distance is diminished ten times, the velocity is increased the square of ten, that is, one hundred times. Now by noting the time it takes the sun, from day to day, to return to the meridian, we learn the comparative velocities with which it moves at different times, and from these we derive the comparative distances of the sun at the corresponding times.

When by either of the foregoing methods, we have learned the relative distances of the sun from the earth at various periods of the year, we may lay down, or *plot* in a diagram like figure 23, a representation of the orbit which the sun apparently describes about the earth, and it will give us the figure of the orbit which the earth really describes about the sun, in its annual revolution.

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120. What conclusions are drawn from the variations in the sun's angular velocity? According to what law does the velocity vary? How may we ascertain the sun's daily rate? What great doctrine is it necessary to be acquainted with, in order to understand the celestial motions?

But neither the revolution of the earth about the sun, nor indeed that of any of the planets, can be well and clearly understood, until we are acquainted with the forces by which their motions are produced, especially with the doctrine of Universal Gravitation. To this subject, therefore, let us next apply our attention.

CHAPTER III.

OF UNIVERSAL GRAVITATION—KEPLER'S LAWS—MOTION IN AN ELLIPTICAL ORBIT—PRECESSION OF THE EQUINOXES.

121. We discover in nature a tendency of every portion of matter towards every other. This tendency is called gravitation. In obedience to this power, a stone falls to the ground and a planet revolves around the sun.

It was once supposed that we could not reason from the phenomena of the earth to those of the heavens; since it was held that the laws of motion might be very different among the heavenly bodies from what we find them to be on this globe; but Galileo and Newton in their researches into nature, proceeded on the idea that nature is uniform in all her works, and that every where the same causes produces the same effects, and that the same effects result from the same causes. That this is a sound principle of philosophy, is proved by the fact, that all the conclusions derived from it in the interpretation of nature are found to be true. Hence by studying the laws of motion as exhibited constantly before our eyes in all terrestrial motions, we are learning

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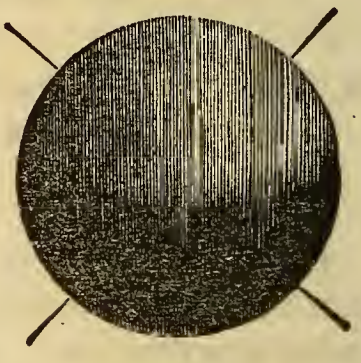
121. What force do we observe in nature? What is this force called? Can we reason from terrestrial to celestial phenomena? On what idea did Galileo and Newton proceed? How is this proved to be a sound principle of philosophy?

the laws that govern the movements of the heavenly bodies.

122. On the earth all bodies are seen to fall towards its center. A stone let fall in any part of the earth, descends immediately to the ground. This may seem to the young learner as so much a matter of course as to require no explanation. But stones fall in exactly opposite directions on opposite sides of the earth, always falling towards the center of the earth from every part exterior to its surface; as when we hold a small needle towards a magnetic ball or load stone, the needle will fly towards the ball, and cling to its surface, to whichever side of the ball it is presented. (Fig. 24.) From this universal descent of bodies near the earth, we infer the existence of some force which draws or impels them, and this invisible force we call the attraction of gravitation, or simply *gravity*.

Fig. 24.



123. By the *laws* of gravity we mean the manner in which it always acts. They are three in number, and are comprehended in the following proposition:

Gravity acts on all matter alike, with a force proportioned to the quantity of matter, and inversely as the square of the distance.

First, gravity acts on *all matter* alike. Every body in nature, whether great or small, whether solid, liquid, or aëriform, exhibits the same tendency to fall towards the center of the earth. Some bodies, indeed, seem less prone to fall than others, and some even appear to rise, as smoke and light vapors. But this is because they are supported by the air; when that is removed, they de-

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122. In what directions do bodies fall in all parts of the earth? Illustrate by figure 24. What is gravity?

scend alike towards the earth; a guinea and a feather, the lightest vapor and the heaviest rocks, fall with equal velocities.

Secondly, the force of gravity is proportioned to the *quantity of matter.* A mass of lead contains perhaps fifty times as much matter as an equal bulk of cotton; yet, if carried beyond the atmosphere, and let fall in absolute space, they would both descend towards the earth with equal speed, until they entered the atmosphere, and were the atmosphere removed they would continue to fall side by side until they reached the earth. Now if the lead contains fifty times as much matter as the cotton, it must take fifty times the force to make it move with equal velocity. If we double the load we must double the team, if we would continue to travel at the same speed as before. Hence, from the fact that bodies of various degrees of density descend alike towards the center of the earth by the force of gravity, we infer that that force is always exerted upon bodies in exact proportion to their quantity of matter.

Thirdly, the force with which gravity acts upon bodies at different distances from the earth, is inversely as the *square of the distance* from the center of the earth. If a pound of lead were carried as far above the earth as from the center to the surface of the earth, it would weigh only one-fourth of a pound; for being twice as far as before from the center of the earth, its weight would be diminished in the proportion of the square of two, that is, four times.

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123. What do we mean by the law of gravity? State the general proposition. Show that gravity acts on all matter alike. How is this consistent with the fact, that some bodies appear to rise? How would all bodies fall in a vacuum? Explain how gravity is proportioned to the quantity of matter. How would equal masses of lead and cotton fall, if carried beyond the atmosphere? What do we infer from the fact, that all bodies fall towards the earth with equal velocities? To what is gravity acting at different distances proportioned? How much would a pound of lead weigh, if carried as far above the earth as from the surface to the center?

124. Bodies falling to the earth by gravity have their velocity continually increased. For since they retain what motion they have and constantly receive more by the continued action of gravity, they must move faster and faster, as a wheel has its velocity constantly accelerated when we continue to apply successive impulses to it.

The spaces which bodies describe, when falling freely by gravity, are as the *squares of the times.* It is found by experiment, that a body will fall from a state of rest 16 $\frac{1}{12}$ feet in one second. In two seconds it will not fall merely through double this space, but through four times this space, that is, through a distance expressed by the square of the time multiplied into $16\frac{1}{12}$. Consequently, in two seconds the fall will be $64\frac{1}{3}$, in three seconds $144\frac{3}{4}$, and in ten seconds $1608\frac{1}{3}$ feet, that is, through one hundred times $16\frac{1}{12}$ feet.

The weight of a body is nothing more than the action of gravity upon it tending to carry it towards the center of the earth. The counterpoise which is placed in the opposite scale by which its weight is estimated, is the force it takes *to hold the body back*, which must be just equal to that by which it endeavors to descend.

125. There is another principle which it is necessary clearly to comprehend before we can understand the motions of the heavenly bodies. It is commonly called the First Law of Motion and is as follows:

Every body perseveres in a state of rest, or of uniform motion in a straight line, unless compelled by some force to change its state. This law has been fully established by experiment, and is conformable to all experience. It embraces several particulars. *First*, A body when at

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124. When a body is falling towards the earth, how is its velocity affected? To what are the spaces described by falling bodies proportioned? How far will a body fall from a state of rest in one second? How far in two seconds? What is the weight of a body?

rest remains so unless some force puts it in motion; and hence it is inferred, when a body is found in motion, that some force must have been applied to it sufficient to have caused its motion. Thus, the fact that the earth is in motion around the sun and around its own axis, is to be accounted for by assigning to each of these motions a force adequate, both in quantity and direction, to produce these motions respectively.

Secondly, When a body is once in motion it will continue to move forever, unless something stops it. When a ball is struck on the surface of the earth, the friction of the earth and the resistance of the air soon stop its motion; when struck on smooth ice it will go much farther before it comes to a state of rest, because the ice opposes much less resistance than the ground; and were there no impediment to its motion it would, when once set in motion, continue to move without end. The heavenly bodies are actually in this condition: they continue to move, not because any new forces are applied to them, but, having been once set in motion, they continue in motion because there is nothing to stop them.

Thirdly, The motion to which a body naturally tends is *uniform;* that is, the body moves just as far the second minute as it did the first, and as far the third as the second, passing over equal spaces in equal times.

Fourthly, A body in motion will move in a *straight line*, unless diverted out of that line by some external force; and the body will resume its straight forward motion, when ever the force that turns it aside is withdrawn. Every body that is revolving in an orbit, like the moon around the earth, or the earth around the sun,

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125. Recite the first law of motion. How has this law been established? What does the fact, that the earth is in motion around the sun imply? How would a ball when once struck continue to move, if it met with no resistance? Why do the heavenly bodies continue to move? What is meant by saying that motion is naturally uniform? In what direction does every revolving body *tend* to move.

tends to move in a straight line which is a tangent* to its orbit.

Let us now see how the foregoing principles, which operate upon bodies on the earth, are extended so as to embrace all bodies in the universe, as in the doctrine of Universal Gravitation. This important principle is thus defined:

126. UNIVERSAL GRAVITATION, *is that influence by which every body in the universe, whether great or small, tends towards every other, with a force which is directly as the quantity of matter, and inversely as the square of the distance.*

As this force acts as though bodies were drawn towards each other by a mutual attraction, the force is denominated *attraction*; but it must be borne in mind, that this term is figurative, and implies nothing respecting the nature of the force.

The *existence* of such a force in nature was distinctly asserted by several astronomers previous to the time of Sir Isaac Newton, but its *laws* were first promulgated by this wonderful man in his Principia, in the year 1687. It is related, that while sitting in a garden, and musing on the cause of the falling of an apple, he reasoned thus:† that, since bodies far removed from the earth fall towards it, as from the tops of towers, and the highest mountains, why may not the same influence extend even to the moon; and if so, may not this be the reason why the moon is made to revolve around the earth, as would be the case with a cannon ball were it projected horizontally near the earth with a certain velocity. According to the first law of motion, the moon, if not continually drawn or impelled towards the earth by some force, would not revolve around it, but would proceed on in a straight line. But going around the earth as she does, in an orbit that is nearly circular, she must be

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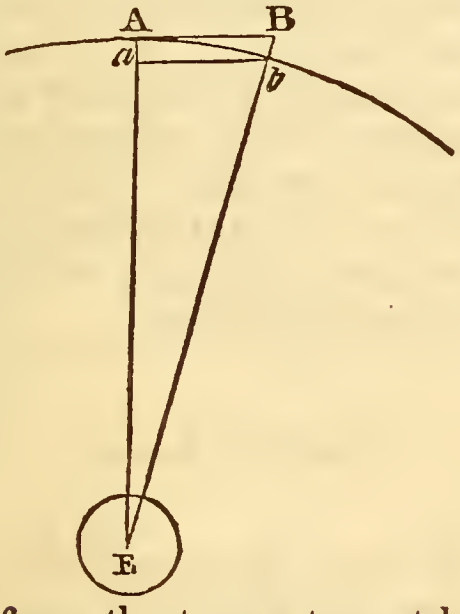
* A tangent is a straight line which touches a curve. Thus AB (Fig 25,) is a tangent to the circle at A.

† Pemberton's View of Newton's Philosophy.

urged towards the earth by some force, which diverts her from a straight course. For let the earth (Fig. 25,) be at E, and let the arc described by the moon in one second of time be *Ab*. Were the moon influenced by no extraneous force, to turn aside, she would have described, not the arc *Ab*, but the straight line AB, and would have been found at the end of the given time at B instead of *b*. She therefore departs from the line in which she tends naturally to move, by the line B*b*, which in small angles may be taken as equal to A*a*.

Fig. 25.



This deviation from the tangent must be owing to *some* extraneous force. Does this force correspond to what the force of gravity exerted by the earth, would be at the distance of the moon? The question resolves itself into this: Would the force of gravity exerted by the earth upon the moon, cause the moon to deviate from her straight forward course towards the earth just as much as she is actually found to deviate? Now we

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126. *Universal Gravitation.*—Define it. Why called attraction? State the historical facts connected with its discovery. How did Sir Isaac Newton reason from the falling of an apple? Explain by figure 25. How is it proved that gravity and no other force causes the moon to revolve about the earth?

know how far the moon is from the earth, namely, sixty times as far as it is from the center to the surface of the earth; and since the force of gravity decreases in proportion to the square of the distance, this force must be 3600 times (which equals the square of 60,) less than at the surface of the earth. This is found, on computation, to be exactly the force required to make the moon deviate to the amount she does from the straight line in which she constantly tends to move; and hence it is inferred that gravity, and no other force than gravity, causes the moon to circulate around the earth.

By this process it was discovered that the law of gravitation extends to the moon. By subsequent inquiries it was found to extend in like manner to all the planets, and to every member of the solar system; and, finally, recent investigations have shown that it extends to the fixed stars. The law of gravitation, therefore, is now established as the grand principle which governs all the motions of the heavenly bodies.

KEPLER'S LAWS.

127. There are three great principles, according to which the motions of the earth and all the planets around the sun are regulated, called *Kepler's Laws*, having been first discovered by the great astronomer whose name they bear. They may appear to the young learner, when he first reads them, dry and obscure; yet they will be easily understood from the explanations that follow; and so important have they proved in astronomical inquiries, that they have acquired for their renowned discoverer the exalted appellation of the *legislator of the skies*.

We will consider each of these laws separately.

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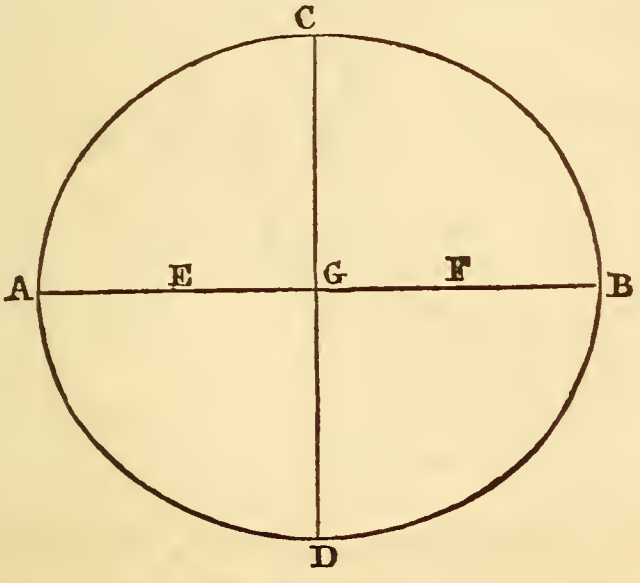
127. *Kepler's Laws.*—Why so called? What appellation has been given to Kepler?

128. FIRST LAW. *The orbits of the earth and all the planets are ellipses, having the sun in the common focus.*

In a circle all the diameters are equal to each other; but if we take a metallic wire or hoop and draw it out on opposite sides, we elongate it into an ellipse, of which the different diameters are very unequal. That which connects the two points most distant from each other is called the *transverse*, and that which is at right angles to this is called the *conjugate* axis. Thus AB (Fig. 26) is the

Fig. 26.



transverse axis and CD the conjugate of the ellipse AB. By such a process of elongating the circle into an ellipse, the center of the circle may be conceived of as drawn opposite ways to E and F, each of which becomes a *focus*, and both together are called the *foci* of the ellipse. The distance GE or GF of the focus from the

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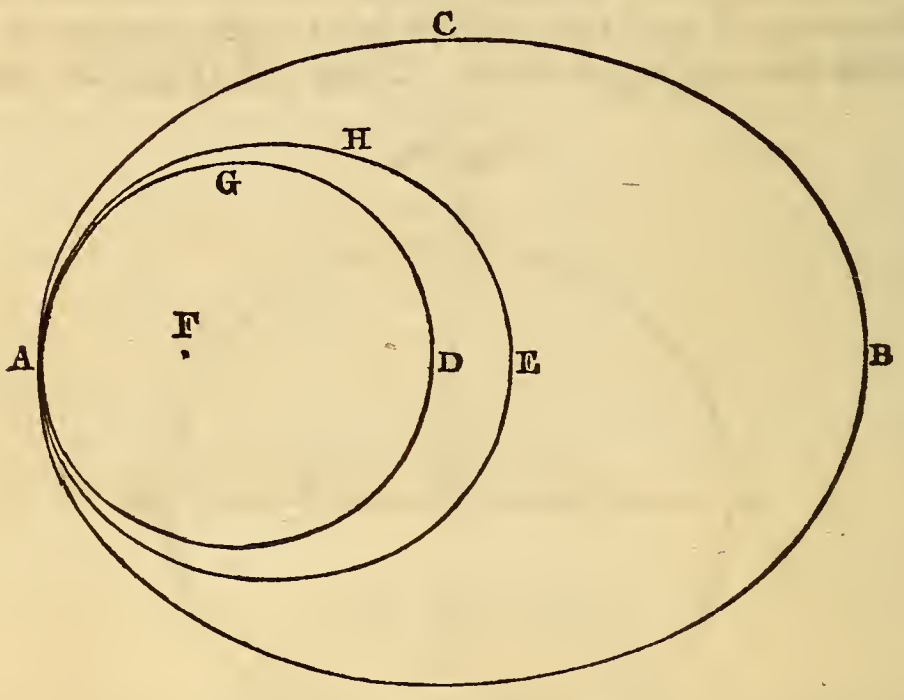
128. Recite the first law. In a circle, how are all the diameters? How are they in an ellipse? What is the longest diameter called? What is the shortest called? Explain by figure 26. What is the eccentricity of the ellipse? How many ellipses may there be having a common focus? Explain figure 26. How eccentric is the earth's orbit?

center is called the *eccentricity* of the ellipse; and the ellipse is said to be more or less eccentric, as the distance of the focus from the center is greater or less.

Now there may be an indefinite number of ellipses having one common focus, but varying greatly in eccentricity. Figure 27 represents such a collection of

Fig. 27.



ellipses around the common focus F, the innermost AGD having a small eccentricity or varying little from a circle, while the outermost ACB is a very eccentric ellipse. The orbits of all the bodies that revolve about the sun, both planets and comets, have, in like manner, a common focus in which the sun is situated, but they differ in eccentricity.

Most of the planets have orbits of very little eccentricity, differing little from circles, but comets move in very eccentric ellipses.

The earth's path around the sun varies so little from a circle, that a diagram representing it truly would scarcely be distinguished from a perfect circle; yet when the comparative distances of the sun from the earth are taken at different seasons of the year, as is explained in Art. 118, we find that the difference between

the greatest and least distances is no less than 3,000,000 miles.

129. SECOND LAW. *The radius vector of the earth, or of any planet, describes equal areas in equal times.*

It will be recollected that the radius vector is a line drawn from the center of the sun to a planet revolving about the sun, (Art. 118.) Thus *Ea*, *Eb*, *Ec*, (Fig. 23,) &c. are successive representations of the radius vector. Now if a planet sets out from *a* and travels round the sun in the direction of *abc*, it will move faster when nearer the sun, as at *a*, than when more remote from it, as at *m*; yet if *ab* and *mn* be arcs described in equal times, then, according to the foregoing law, the space *Eab* will be equal to the space *Emn*; and the same is true of all the other spaces described in equal times. Although the figure *Eab* is much shorter than *Emn*, yet its greater breadth exactly counterbalances the greater length of those figures which are described by the radius vector where it is longer.

130. THIRD LAW. *The squares of the periodical times are as the cubes of the mean distances from the sun.*

The periodical time of a body is the time it takes to complete its orbit in its revolution about the sun. Thus the earth's periodic time is one year, and that of the planet Jupiter is about twelve years. As Jupiter takes so much longer time to travel round the sun than the earth does, we might suspect that his orbit was larger than that of the earth, and of course that he was at a greater distance from the sun, and our first thought might be that he was probably twelve times as far off; but Kepler discovered that the distances did not increase as fast as the times increased, but that the planets which

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129. State Kepler's second law. Explain by figure 23, p. 88.

130. State Kepler's third law. What is meant by the periodical time of a body? Do planets move faster or slower as they are more distant from the sun? Explain the law.

are more distant from the sun actually move slower than those which are nearer. After trying a great many proportions, he at length found that if we take the squares of the periodic times of two planets, the greater square contains the less, just as often as the cube of the distance of the greater contains that of the less. This fact is expressed by saying, that the squares of the periodic times are to one another as the cubes of the distances.

This law is of great use in determining the distances of all the planets from the sun, as we shall see more fully hereafter.

MOTION IN AN ELLIPTICAL ORBIT.

131. Let us now endeavor to gain a just conception of the forces by which the earth and all the planets are made to revolve about the sun.

In obedience to the first law of motion, every moving body *tends* to move in a straight line; and were not the planets deflected continually towards the sun by the force of attraction, these bodies as well as others would move forward in a rectilineal direction. We call the force by which they tend to such a direction the *projectile force*, because its effects are the same as though the body were originally projected from a certain point in a certain direction. It is an interesting problem for mechanics to solve, what was the nature of the impulse originally given to the earth, in order to impress upon it its two motions, the one around its own axis, the other around the sun. If struck in the direction of its center of gravity it might receive a forward motion, but no rotation on its axis. It must, therefore, have been impelled by a force, whose direction did not pass through its

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131. Explain how a body is made to revolve in an orbit, under the action of two forces. What is meant by the projectile force? How must the earth have been impelled in order to receive its present motions? How illustrated by the motions of a top?

center of gravity. Bernouilli, a celebrated mathematician, has calculated that the impulse must have been given very nearly in the direction of the center, the point of projection being only the 165th part of the earth's radius from the center. This impulse alone would cause the earth to move in a right line: gravitation towards the sun causes it to describe an orbit. Thus a top spinning on a smooth plane, as that of glass or ice, impelled in a direction not coinciding with that of the center of gravity, may be made to imitate the two motions of the earth, especially if the experiment is tried in a concave surface like that of a large bowl. The resistance occasioned by the surface on which the top moves, and that of the air, will gradually destroy the force of projection and cause the top to revolve in a smaller and smaller orbit; but the earth meets with no such resistance, and therefore makes both her days and years of the same length from age to age. A body, therefore, revolving in an orbit about a center of attraction, is constantly under the influence of two forces,—the *projectile* force, which tends to carry it forward in a straight line which is a tangent to its orbit, and the *centripetal* force, by which it tends towards the center.

132. As an example of a body revolving in an orbit under the influence of two forces, suppose a body placed at any point P (Fig. 28,) above the surface of the earth, and let PA be the direction of the earth's center. If the body were allowed to move without receiving any impulse, it would descend to the earth in the direction PA with an accelerated motion. But suppose that at the moment of its departure from P, it receives an impulse in the direction PB, which would carry it to B in the time the body would fall from P to A; then under the influence of both forces it would descend along the curve PD. If a stronger impulse were given it in

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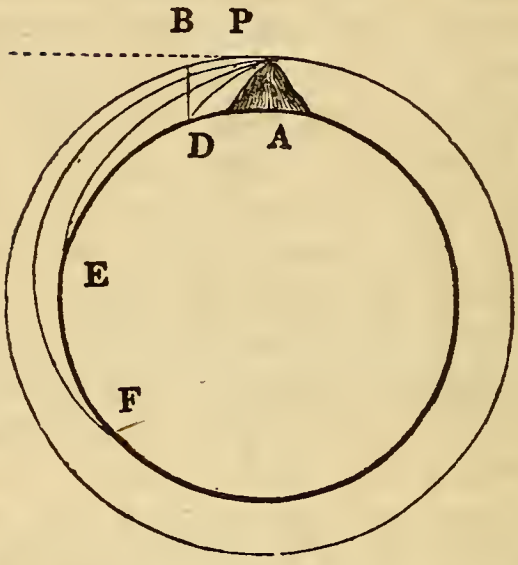
132. Explain figure 28. How might a body be made to circulate quite around the earth?

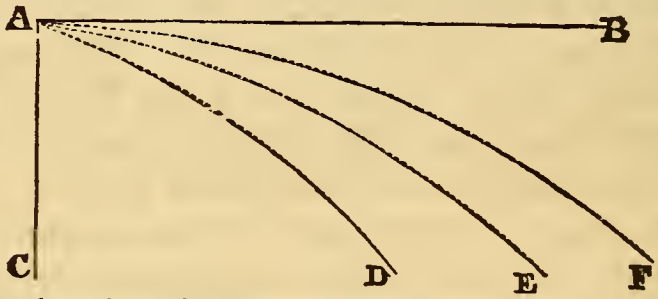
Fig. 28.



the direction PB, it would describe a larger curve PE, or PF, or finally, it would go quite round the earth and return again to P.

133. The most simple example we have of the combined action of these two forces, is the motion of a missile thrown from the hand, or of a ball fired from a cannon. It is well known that the particular form of the curve described by the projectile, in either case, will depend upon the velocity with which it is thrown. In each case the body will begin to move in the line of direction in which it is projected, but it will soon be deflected from that line towards the earth. It will however continue nearer to the line of projection as the ve-

Fig. 29.



locity of projection is greater. Thus let AB (Fig. 29,)

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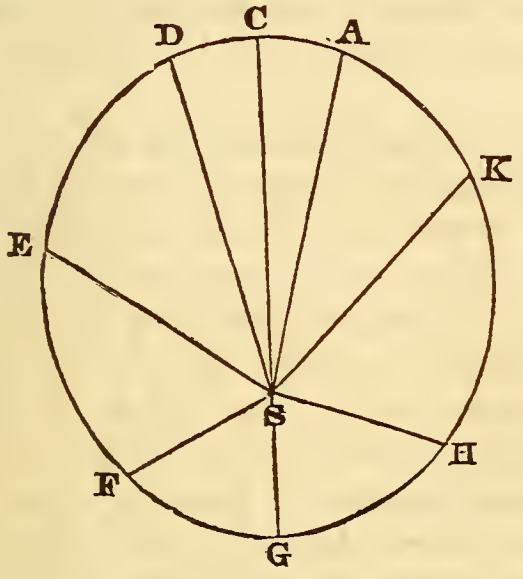
133. When a cannon ball is fired with different velocities, when is its motion nearest to the line of projection?

perpendicular to AC represent the line of projection. The body will, in every case, commence its motion in the line AB, which will therefore be the tangent to the curve it describes; but if it be thrown with a small velocity, it will soon depart from the tangent, describing the line AD; with a greater velocity it will describe a curve nearer to the tangent, as AE; and with a still greater velocity it will describe the curve AF.

134. In figure 30, suppose the planet to have passed the point C with so small a velocity, that the attraction of the sun bends its path very much, and causes it immediately to begin to approach towards the sun; the sun's attraction will increase its velocity as it moves through D, E, and F. For the sun's attractive force on

Fig. 30.



the planet, when at D, is acting in the direction DS, and, on account of the small inclination of DE to DS, the force acting in the line DS helps the planet forward in the path DE, and thus increases its velocity. In like manner, the velocity of the planet will be continually increasing as it passes through E, and F; and though

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134. Explain the motion of a planet in an elliptical orbit, from figure 30.

the attractive force, on account of the planet's nearness, is much increased, and tends therefore to make the orbit more curved, yet the velocity is also so much increased that the orbit is not more curved than before. The same increase of velocity occasioned by the planet's approach to the sun, produces a greater increase of centrifugal force which carries it off again. We may see also why, when the planet has reached the most distant parts of its orbit, it does not entirely fly off, and never return to the sun. For when the planet passes along H, K, A, the sun's attraction retards the planet, just as gravity retards a ball rolled up hill; and when it has reached C, its velocity is very small, and the attraction at the center of force causes a great deflection from the tangent, sufficient to give its orbit a great curvature, and the planet turns about, returns to the sun, and goes over the same orbit again. As the planet recedes from the sun, its centrifugal force diminishes faster than the force of gravity, so that the latter finally preponderates.

135. We may imitate the motion of a body in its orbit by suspending a small ball from the ceiling by a long string. The ball being drawn out of its place of rest, (which is directly under the point of suspension,) it will tend constantly towards the same place by a force which corresponds to the force of attraction of a central body. If an assistant stands under the point of suspension, his head occupying the place of the ball when at rest, the ball may be made to revolve about his head as the earth or any planet revolves about the sun. By projecting the ball in different directions, and with different degrees of velocity, we may make it describe different orbits, exemplifying principles which have been explained in the foregoing articles.

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135. How may we imitate the motion of a body in its orbit? How may we make the ball describe different orbits?

PRECESSION OF THE EQUINOXES.

136 THE PRECESSION OF THE EQUINOXES, *is a slow but continual shifting of the equinoctial points from east to west.*

Suppose that we mark the exact place in the heavens where, during the present year, the sun crosses the equator, and that this point is close to a certain star; next year the sun will cross the equator a little way westward of that star, and thus every year a little farther westward, so that in a long course of ages, the place of the equinox will occupy successively every part of the ecliptic, until we come round to the same star again. As, therefore, the sun, revolving from west to east in his apparent orbit, comes round towards the point where it left the equinox, it meets the equinox before it reaches that point. The appearance is as though the equinox *goes forward* to meet the sun, and hence the phenomenon is called the *Precession of the Equinoxes*, and the fact is expressed by saying that the equinoxes retrograde on the ecliptic, until the line of the equinoxes makes a complete revolution from east to west. The equator is conceived as *sliding* westward on the ecliptic, always preserving the same inclination to it, as a ring placed at a small angle with another of nearly the same size, which remains fixed, may be slid quite around it, giving a corresponding motion to the two points of intersection. It must be observed, however, that this mode of conceiving of the precession of the equinoxes is purely imaginary, and is employed merely for the convenience of representation.

137. The *amount of precession* annually is 50.″1; whence, since there are 3600″ in a degree, and 360° in

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136. *Precession of the Equinoxes.*—Define it. If the sun crosses the equator near a certain star this year, where will it cross it next year? Why is the fact called the precession of the equinoxes? How is the equator conceived as moving with regard to the ecliptic?

the whole circumference, and consequently, 1296000″, this sum divided by 50.1 gives 25868 years for the period of a complete revolution of the equinoxes.

138. Suppose now we fix to the center of each of the two rings, (Art. 136,) a wire representing its axis, one corresponding to the axis of the ecliptic, the other to that of the equator, the extremity of each being the pole of its circle. As the ring denoting the equator turns round on the ecliptic, which with its axis remains fixed, it is easy to conceive that the axis of the equator revolves around that of the ecliptic, and the pole of the equator around the pole of the ecliptic, and constantly at a distance equal to the inclination of the two circles. To transfer our conceptions to the celestial sphere, we may easily see that the axis of the diurnal sphere, (that of the earth produced, Art. 15,) would not have its pole constantly in the same place among the stars, but that this pole would perform a slow revolution around the pole of the ecliptic from east to west, completing the circuit in about 26,000 years. Hence the star which we now call the pole star, has not always enjoyed that distinction, nor will it always enjoy it hereafter. When the earliest catalogues of the stars were made, this star was 12° from the pole. It is now 1° 33′, and will approach still nearer ; or to speak more accurately, the pole will come still nearer to this star, after which it will leave it, and successively pass by others. In about 13,000 years, the bright star α Lyræ, which lies on the circle of revolution opposite to the present pole star,

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137. What is the amount of precession annually? In what time will the equinoxes perform a complete revolution?

138. Illustrate the precession of the equinoxes by an apparatus of wires. How is the pole of the earth situated with respect to the stars at different times? Has the present pole star always been such? What will be the pole star 13,000 years hence? Will this cause affect the elevation of the north pole above the horizon?

will be within 5° of the pole, and will constitute the Pole Star. As α Lyræ now passes near our zenith, the learner might suppose that the change of position of the pole among the stars would be attended with a change of altitude of the north pole above the horizon. This mistaken idea is one of the many misapprehensions which result from the habit of considering the horizon as a fixed circle in space. However the pole might shift its position in space, we should still be at the same distance from it, and our horizon would always reach the same distance beyond it.

139. *The time occupied by the sun in passing from the equinoctial point round to the same point again, is called the* TROPICAL YEAR. As the sun does not perform a complete revolution in this interval but falls short of it 50.″1, the tropical year is shorter than the sidereal by 20m. 20s. in mean solar time, this being the time of describing an arc of 50.″1 in the annual revolution.* The changes produced by the precession of the equinoxes in the apparent places of the circumpolar stars, have led to some interesting results in *chronology*. In consequence of the retrograde motion of the equinoctial points, the *signs* of the ecliptic, do not correspond at present to the *constellations* which bear the same names, but lie about one whole sign or 30° westward of them. Thus, that division of the ecliptic which is called the sign Taurus, lies in the constellation Aries, and the sign Gemini in the constellation Taurus. Undoubtedly however when the ecliptic was thus first divided, and the divisions named, the several constellations lay in the respective divisions which bear their names. How long is it, then, since our zodiac was formed?

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139. Define the tropical year. How much shorter is the tropical than the sidereal year? How has the precession of the equinoxes been applied in Chronology?

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* 59′ 8.″3 : 24h. : : 50.″1 : 20m. 20s.

50.″1 : 1 year : : 30°(=108000″) : 2155.6 years.

The result indicates that the present divisions of the zodiac, were made soon after the establishment of the Alexandrian school of astronomy.

CHAPTER IV.

OF THE MOON—PHASES—REVOLUTIONS.

140. NEXT to the Sun the Moon naturally claims our attention. She is an attendant or satellite to the earth, around which she revolves at the distance of nearly 240,000 miles, or more exactly 238,545 miles. Her angular diameter is about half a degree, and her real diameter 2160 miles. She is therefore a comparatively small body, being only one forty-ninth part as large as the earth.

The moon shines by reflected light borrowed from the sun, and when full exhibits a disk of silvery brightness, diversified by extensive portions partially shaded. These dusky spots are generally said to be land, and the brighter parts water; but astronomers tell us that if either are water, it must be the darker portions. Land by scattering the rays of the sun's light would appear more luminous than the ocean which reflects the light like a mirror. By the aid of the telescope, we see undoubted signs of a varied surface, in some parts composed of extensive tracts of level country, and in others exceedingly broken by mountains and valleys.

141. The line which separates the enlightened from the dark portions of the moon's disk, is called the *Ter-*

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140. The *Moon.*—What relation has the moon to the earth? State her distance, diameter and bulk. Is her light direct or reflected? What are the dark places in the moon generally understood to be? Why would water appear darker than land? What does the telescope reveal to us respecting the moon?

minator. (See Frontispiece.) As the terminator traverses the disk from new to full moon, it appears through the telescope exceedingly broken in some parts, but smooth in others, indicating that portions of the lunar surface are uneven while others are level. The broken regions appear brighter than the smooth tracts. The latter have been taken for seas, but it is supposed with more probability that they are extensive plains, since they are still too uneven for the perfect level assumed by bodies of water. That there are *mountains* in the moon, is known by several distinct indications. First, when the moon is increasing, certain spots are illuminated sooner than the neighboring places, appearing like bright points beyond the terminator, within the dark part of the disk, in the same manner as the tops of mountains on the earth are tipped with the light of the sun, in the morning, while the regions below are still dark. Secondly, after the terminator has passed over them, they project shadows upon the illuminated part of the disk, always opposite to the sun, corresponding in shape to the form of the mountain, and undergoing changes in length from night to night, according as the sun shines upon that part of the moon more or less obliquely. Many individual mountains rise to a great height in the midst of plains, and there are several very remarkable mountainous groups, extending from a common center in long chains.

142. That there are also *valleys* in the moon, is equally evident. The valleys are known to be truly such, particularly by the manner in which the light of the sun falls upon them, illuminating the part opposite to the sun while the part adjacent is dark, as is the case when the light of a lamp shines obliquely into a china

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141. Define the terminator. What do we learn from its rugged appearance? State the proofs of mountains in the moon.

142. State the proofs of valleys in the moon. When is the best time for viewing the mountains and valleys of the moon.

cup. These valleys are often remarkably regular, and some of them almost perfect circles. In several instances, a circular chain of mountains surrounds an extensive valley, which appears nearly level, except that a sharp mountain sometimes rises from the center. The best time for observing these appearances is near the first quarter of the moon, when half the disk is enlightened;* but in studying the lunar geography, it is expedient to observe the moon every evening from new to full, or rather through her entire series of changes.

143. The various places on the moon's disk have received appropriate *names*. The dusky regions, being formerly supposed to be seas, were named accordingly; and other remarkable places have each two names, one derived from some well known spot on the earth, and the other from some distinguished personage. Thus the same bright spot on the surface of the moon is called *Mount Sinai* or *Tycho*, and another, *Mount Etna* or *Copernicus*. The names of individuals, however, are more used than the others. The frontispiece exhibits the telescopic appearance of the full moon. A few of the most remarkable points have the following names, corresponding to the numbers and letters on the map. (See *Frontispiece.*)

1. Tycho,	A. Mare Humorum,
2. Kepler,	B. Mare Nubium,
3. Copernicus,	C. Mare Imbrium,
4. Aristarchus,	D. Mare Nectaris,
5. Helicon,	E. Mare Tranquilitatis,
6. Eratosthenes,	F. Mare Serenitatis,
7. Plato,	G. Mare Fecunditatis,
8. Archimedes,	H. Mare Crisium.
9. Eudoxus,	
10. Aristotle,	

* It is earnestly recommended to the student of astronomy, to examine the moon repeatedly with the best telescope he can command, using low powers at first, for the sake of a better light

The frontispiece represents the appearance of the moon in the telescope when full and when five days old. In the latter cut, the learner will remark the rough, rugged appearance of the terminator; the illuminated points beyond the terminator within the dark part of the moon, which are the tops of mountains; and the numerous circular spaces, which exhibit valleys or caverns surrounded by mountainous chains. Those circles which are near the terminator into which the sun's light shines very obliquely, cast deep shadows on the sides opposite the sun. Those more remote from the terminator, and farther within the illuminated part of the moon, into which the sun shines more directly, have a greater portion illuminated, with shorter shadows; and those which lie near the edge of the moon, most distant from the terminator, are of an oval figure, being presented obliquely to the eye.

144. The heights of the lunar mountains, and the depths of the valleys, can be estimated with a considerable degree of accuracy. Some of the mountains are as high as five miles, and the valleys in some instances are four miles deep. Hence it is inferred that the surface of the moon is more broken and irregular than that of the earth, its mountains being higher and its valleys deeper in proportion to its magnitude than that of the earth. The lunar mountains in general, exhibit an ar-

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143. How are places in the moon named? Point out the most remarkable places on the map of the full moon. Point out the mountains, valleys, and craters, on the cut, which represents the moon five days old.

144. Specify the heights of some of the lunar mountains. Is the surface of the moon more or less broken than that of the earth? Are the mountains like or unlike ours? What is the first variety? What is the shape of the insulated mountains? How can their heights be calculated? What is said of the second variety, the mountain ranges? What is said of the circular ranges? What is said of the central mountains?

rangement and an aspect very different from the mountain scenery of our globe. They may be arranged under the four following varieties.

First, *Insulated Mountains*, which rise from plains nearly level, shaped like a sugar loaf, which may be supposed to present an appearance somewhat similar to Mount Etna, or the Peak of Teneriffe. The shadows of these mountains, in certain phases of the moon, are as distinctly perceived, as the shadow of an upright staff, when placed opposite to the sun; and these heights can be calculated from the length of their shadows. Some of these mountains being elevated in the midst of extensive plains, would present to a spectator on their summits, magnificent views of the surrounding regions.

Secondly, *Mountain Ranges*, extending in length two or three hundred miles. These ranges bear a distant resemblance to our Alps, Appenines, and Andes; but they are much less in extent. Some of them appear very rugged and precipitous, and the highest ranges are in some places more than four miles in perpendicular altitude. In some instances, they are nearly in a straight line from northeast to southwest, as in that range called the *Appenines;* in other cases they assume the form of a semicircle or crescent.

Thirdly, *Circular Ranges*, which appear on almost every part of the moon's surface, particularly in its southern regions. This is one grand peculiarity of the lunar ranges, to which we have nothing similar on the earth. A plain, and sometimes a large cavity, is surrounded with a circular ridge of mountains, which encompasses it like a mighty rampart. These annular ridges and plains are of all dimensions, from a mile to forty or fifty miles in diameter, and are to be seen in great numbers over every region of the moon's surface; they are most conspicuous, however, near the upper and lower limbs about the time of half moon.

The mountains which form these circular ridges are of different elevations, from one fifth of a mile to three and a half miles, and their shadows cover one half of the plain at the base. These plains are sometimes on

a level with the general surface of the moon, and in other cases they are sunk a mile or more below the level of the ground, which surrounds the exterior circle of the mountains.

Fourthly, *Central Mountains*, or those which are placed in the middle of circular plains. In many of the plains and cavities surrounded by circular ranges of mountains there stands a single insulated mountain, which rises from the center of the plain, and whose shadow sometimes extends in the form of a pyramid half across the plain or more to the opposite ridges. These central mountains are generally from half a mile to a mile and a half in perpendicular altitude. In some instances they have two and sometimes three different tops, whose shadows can be easily distinguished from each other. Sometimes they are situated towards one side of the plain or cavity, but, in the great majority of instances, their position is nearly or exactly central. The lengths of their bases vary from five to about fifteen or sixteen miles.

145. The *Lunar Caverns* form a very peculiar and prominent feature of the moon's surface, and are to be seen throughout almost every region, but are most numerous in the southwest part of the moon. Nearly a hundred of them, great and small, may be distinguished in that quarter. They are all nearly of a circular shape, and appear like a very shallow egg-cup. The smaller cavities appear within almost like a hollow cone, with the sides tapering towards the center; but the larger ones have for the most part, flat bottoms, from the center of which there frequently rises a small steep conical hill, which gives them a resemblance to the circular ridges and central mountains before described. In some instances their margins are level with the general surface of the moon, but in most cases they are encircled

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145. Lunar Caverns.—What is said of their number, shape and appearances ?

with a high annular ridge of mountains, marked with lofty peaks. Some of the larger of these cavities contain smaller cavities of the same kind and form, particularly in their sides. The mountainous ridges which surround these cavities, reflect the greatest quantity of light; and hence that region of the moon in which they abound, appears brighter than any other. From their lying in every possible direction, they appear at and near the time of full moon, like a number of brilliant streaks or radiations. These radiations appear to converge towards a large brilliant spot, surrounded by a faint shade, near the lower part of the moon which is named *Tycho*, (Frontispiece, 1,) which may be easily distinguished even by a small telescope. The spots named Kepler and Copernicus, are each composed of a central spot with luminous radiations.*

146. Dr. Herschel is supposed also to have obtained decisive evidence of the existence of *volcanoes* in the moon, not only from the light afforded by their fires, but also from the formation of new mountains by the accumulation of matter where fires had been seen to exist, and which remained after the fires were extinct.

147. Some indications of an *atmosphere* about the moon have been obtained, the most decisive of which are derived from appearances of twilight, a phenomenon that implies the presence of an atmosphere. Similar indications have been detected, it is supposed, in eclipses of the sun, denoting a transparent refracting medium encompassing the moon.

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146. Volcanoes.—What proofs are there of their having existed in the moon?

147. What evidence is there of a lunar atmosphere?

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* The foregoing accurate description of the lunar mountains and caverns is from "Dick's Celestial Scenery."

148. It has been a question with astronomers, whether there is *water* in the moon? The general opinion is that there is none. If there were any, we should expect to see clouds; or at least we should expect to find the face of the moon occasionally obscured by clouds; but this is not the case, since the spots on the moon's disk, when our sky is clear, are always in full view. The deep caverns, moreover, seen in those dusky spots which were supposed to be seas, are unfavorable to the supposition, that they are surrounded by water; and the terminator when it passes over these places is, as already remarked, too uneven to permit us to suppose that these tracts are seas.

149. The improbability of our ever identifying *artificial structures* in the moon, may be inferred from the fact that a line one mile in length in the moon subtends an angle at the eye of only about one second. If, therefore, works of art were to have a sufficient horizontal extent to become visible, they can hardly be supposed to attain the necessary elevation, when we reflect that the height of the great pyramid of Egypt is less than the sixth part of a mile. Still less probable is it that we shall ever discover any inhabitants in the moon. The greatest magnifying power that has ever been applied with distinctness, to the moon, does not much exceed a thousand times, bringing the moon apparently a thousand times nearer to us than when seen by the naked eye. But this implies a distance still of 240 miles; and

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148. Is there water in the moon? What proofs are there to the contrary?

149. Is it probable that artificial structures in the moon will ever be identified? How high must they be, in order to be seen distinct from the surface? Is it probable that we shall ever be able to recognize inhabitants in the moon? What is the greatest magnifying power of the telescope that has ever been applied to the moon? If we could magnify the moon 10,000 times what would still be her apparent distance? What inherent difficulty is there in employing very great magnifiers?

could we magnify the moon ten thousand times, her apparent distance would still be twenty-four miles, a distance too great to distinguish living beings. Moreover, when we use such high magnifiers in the telescope, our field of view is necessarily exceedingly small, so that it would be a mere point that we could view at a time. This difficulty is inherent in the very nature of telescopes, namely, that the field of view is reduced as the magnifying power is increased; and we magnify the vapors and the undulations of the atmosphere, as well as the moon, and by this means impair the medium so much that we should not be able to see anything with distinctness. It is only to such minute objects as a star, that very high powers of the telescope can ever be applied.

150. Some writers, however, suppose that possibly we may trace indications of lunar inhabitants in their works, and that they may, in like manner, recognize the existence of the inhabitants of our planet. An author who has reflected much on subjects of this kind, reasons as follows: A navigator who approaches within a certain distance of a small island, although he perceives no human being upon it, can judge with certainty, that it is inhabited, if he perceives human habitations, villages, cornfields, or other traces of cultivation. In like manner, if we could perceive changes or operations in the moon, which could be traced to the agency of intelligent beings, we should then obtain satisfactory evidence, that such beings exist on that planet; and it is thought possible that such operations may be traced. A telescope which magnifies 1200 times, will enable us to perceive, as a visible point on the surface of the moon, an object whose diameter is only about 300 feet. Such

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150. What have some writers supposed with respect to the probability of our tracing marks of living beings on the moon? How is it proposed to have the moon examined for this purpose?

an object is not larger than many of our public edifices; and, therefore, were any such edifices rearing in the moon, or were a town or city extending its boundaries, or were operations of this description carrying on in a district where no such edifices had previously been erected, such objects and operations might probably be detected by a minute inspection. Were a multitude of living creatures moving from place to place in a body, or were they even encamping in an extensive plain, like a large army, or like a tribe of Arabs in the desert, and afterwards removing, it is possible that such changes might be traced by the difference of shade or color, which such movements would produce. In order to detect such minute objects and operations, it would be requisite that the surface of the moon should be distributed among at least a hundred astronomers, each having a spot or two allotted to him, as the object of his more particular investigation, and that the observations be continued for a period of at least thirty or forty years, during which time certain changes would probably be perceived, arising either from physical causes, or from the operations of living agents.*

151. It has sometimes been a subject of speculation, whether it might be possible, by any symbols, to correspond with the inhabitants of the moon. It has been suggested, that if some vast geometrical figure, as a square or a triangle, were erected on the plains of Siberia, it might be recognized by the lunarians, and answered by some corresponding signal. Some geometrical figure would be peculiarly appropriate for such a telegraphic commerce with the inhabitants of another sphere, since these are simple ideas common to all minds.

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151. How is it proposed to carry on a telegraphic communication with the lunarians?

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* Dick's Celestial Scenery, Ch. IV.

PHASES OF THE MOON.

152. The changes of the moon, commonly called her Phases, arise from different portions of her illuminated side being turned towards the earth at different times. When the moon is first seen after the setting sun, her form is that of a bright crescent, on the side of the disk next to the sun, while the other portions of the disk shine with a feeble light, reflected to the moon from the earth. Every night we observe the moon to be farther and farther eastward of the sun, and at the same time the crescent enlarges, until, when the moon has reached an elongation from the sun of 90°, half her visible disk is enlightened, and she is said to be in her *first quarter*. The terminator, or line which separates the illuminated from the dark part of the moon, is convex towards the sun from the new moon to the first quarter, and the moon is said to be *horned*. The extremities of the crescent are called *cusps*. At the first quarter, the terminator becomes a straight line, coinciding with a diameter of the disk; but after passing this point, the terminator becomes concave towards the sun, bounding that side of the moon by an elliptical curve, when the moon is said to be *gibbous*. When the moon arrives at the distance of 180° from the sun, the entire circle is illuminated, and the moon is full. She is then *in opposition* to the sun, rising about the time the sun sets. For a week after the full, the moon appears gibbous again, until, having arrived within 90° of the sun, she resumes the same form as at the first quarter, being then at her *third quarter*. From this time until new moon, she exhibits again the form of a crescent before the rising sun, until, approaching her *conjunction* with the

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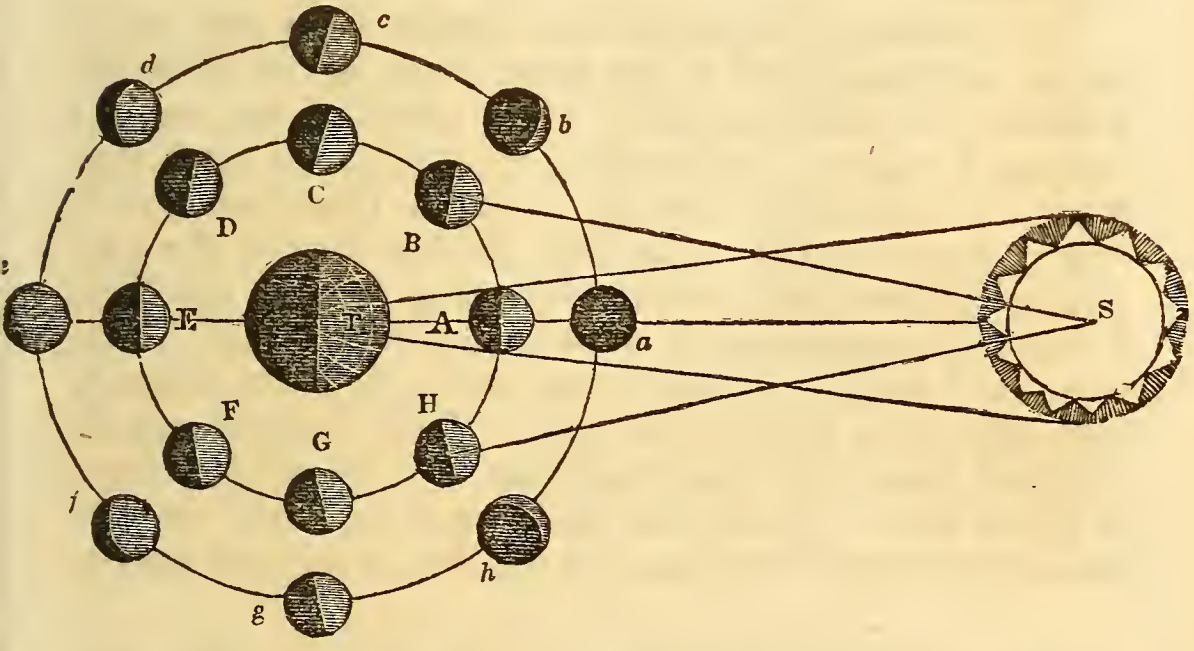
152. *Phases of the Moon.*—Whence do they rise? State the successive appearances of the moon from new to full. In what parts of her revolution is she horned, and in what parts gibbous? When is she said to be in conjunction, and when in opposition? What are the syzigies, quadratures, and octants? Define the circle of illumination, and the circle of the disk.

sun, her narrow thread of light is lost in the solar blaze; and finally, at the moment of passing the sun, the dark side is wholly turned towards us, and for some time we lose sight of the moon.

The two points in the orbit corresponding to new and full moon respectively, are called by the common name of *syzigies;* those which are 90° from the sun are called *quadratures;* and the points half way between the syzigies and quadratures are called *octants.* The circle which divides the enlightened from the unenlightened hemisphere of the moon, is called the *circle of illumination:* that which divides the hemisphere that is turned towards us from the hemisphere that is turned from us, is called the *circle of the disk.*

153. As the moon is an opake body of a spherical figure, and borrows her light from the sun, it is obvious

Fig. 31



that that half only which is towards the sun can be illuminated. More or less of this side is turned towards the earth, according as the moon is at a greater or less elongation from the sun. The reason of the different phases will be best understood from a diagram. Therefore let T (Fig. 31,) represent the earth, and S the sun.

Let A, B, C, &c. be successive positions of the moon At A the entire dark side of the moon being turned towards the earth, the disk would be wholly invisible. At B, the circle of the disk cuts of a small part of the enlightened hemisphere, which appears in the heavens at *b*, under the form of a crescent. At C, the first quarter the circle of the disk cuts off half the enlightened hemisphere, and a half moon is seen at *c*. In like manner it will be seen that the appearances presented at D, E, F, &c. must be those represented at *d*, *e*, *f*. If a round body, as an apple, suspended by a string, be carried around a lamp, the eye remaining fixed opposite to it at the same level, the various phases of the moon will be exhibited.

REVOLUTIONS OF THE MOON.

154. *The moon revolves around the earth from west to east, making the entire circuit of the heavens in about* $27\frac{1}{4}$ *days.*

The period of the moon's revolution from any point in the heavens round to the same point again, is called a *month.* A *sidereal month* is the time of the moon's passing from any star, until it returns to the same star again. A *synodical month*, so called from two Greek words implying that at the end of this period the two bodies (the sun and moon) come together, is the time from one conjunction or new moon to another. The synodical month is about $29\frac{1}{2}$ days, or more exactly, 29d. 12h. 44m. 2s.8 = 29.53 days. The sidereal month is about two days shorter, being 27d. 7h. 43m. 11s.5. or 27.32 days. As the sun and moon are both revolving in the same direction, and the sun is moving nearly

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153. How much of the moon is illuminated at once? Explain the phases of the moon from figure 31.

154. Define a month. Define a sidereal month. Also a synodical month. Why so called? What is the length of the synodical month? Also of the sidereal month? What is the moon's daily motion?

a degree a day, during the 27 days of the moon's revolution, the sun must have moved 27°. Now since the moon passes over 360° in 27.32 days, her daily motion must be 13° 17′. It must therefore evidently take about two days for the moon to overtake the sun.

155. *The moon's orbit is inclined to the ecliptic in an angle of about* 5° (5° 8′ 48″.) The moon crosses the ecliptic in two opposite points called her *nodes.* That which the moon crosses from south to north, is called her *ascending* node, that which she crosses from north to south, her *descending* node. The moon, therefore, is never seen far from the ecliptic, but the path she pursues through the skies, is very nearly the same as that of the sun in his annular revolution around the earth.

156. The moon, at the same age, crosses the meridian at different altitudes at different seasons of the year; and accordingly it is said to run sometimes high and sometimes low. The full moon, for example, will appear much farther in the south when on the meridian at one period of the year than at another. The reason of this may be explained as follows. When the sun is in the part of the ecliptic south of the equator, the earth and of course the moon, which always keeps near to the earth, is in the part north of the equator. At such times, therefore, the new moons, which are always seen in the part of the heavens where the sun is, will run far south, while the full moons, which are always in the opposite part of the heavens from the sun, will run high. Such is the case during the winter months; but,

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155. How much is the moon's orbit inclined to the ecliptic? Define the nodes. What is the ascending and what the descending node?

156. Why does the moon run high and low? At what season of the year are the full moons longest above the horizon? Explain how this operates favorably to those who are near the pole.

in the summer, when the sun is towards the northern tropic and the earth towards the southern, the new moons run high and the full moons low. This arrangement gives us a great advantage in respect to the amount of light received from the moon; since the full moon is longest above the horizon during the long nights of winter, when her presence is most needed. This circumstance is especially favorable to the inhabitants of the polar regions, the moon, when full, traversing that part of her orbit which lies north of the equator, and of course above the horizon of the north pole, and traversing the portion that lies south of the equator, and below the polar horizon, when new. During the polar winter, therefore, the moon, during her second and third quarters, when she gives most light, is commonly above the horizon, while the sun is absent; whereas, during summer, while the sun is present and the light is not needed, during her second and third quarters, she is below the horizon.

157. About the time of the autumnal equinox, the moon when near the full, rises about sunset for a number of nights in succession; and as this is, in England, the period of harvest, the phenomenon is called the *Harvest Moon.* To understand the reason of this, since the moon is never far from the ecliptic, we will suppose her progress to be in the ecliptic. If the moon moved in the equator, then, since this great circle is at right angles to the axis of the earth, all parts of it, as the earth revolves, cut the horizon at the same constant angle. But the moon's orbit, or the ecliptic, which is here taken to represent it, being oblique to the equator, cuts the horizon at different angles in different parts, as will easily be seen by reference to an artificial globe. When the first of Aries, or vernal equinox, is in the

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157. Why is the harvest moon so called? Explain its cause. How is the moon's orbit inclined to the horizon at different times?

eastern horizon, it will be seen that the ecliptic, (and consequently the moon's orbit,) makes its least angle with the horizon. Now, at the autumnal equinox, the sun being in Libra, the moon at the full, when she is always opposite to the sun, is in Aries, and rises when the sun sets. On the following evening, although she has advanced in her orbit about 13°, yet her progress being oblique to the horizon, and at a small angle with it, she will be found at this time but a little way below the horizon, compared with the point where she was at sunset the preceding evening. She therefore rises but little later, and so for a week only a little later each evening than she did the preceding night.

158. *The moon turns on its axis in the same time in which it revolves around the earth.*

This is known by the moon's always keeping nearly the same face towards us, as is indicated by the telescope, which could not happen unless her revolution on her axis kept pace with her motion in her orbit. Thus it will be seen by inspecting figure 22, that the earth turns different faces towards the sun at different times; and if a ball having one hemisphere white and the other black be carried around a lamp, it will easily be seen that it cannot present the same face constantly towards the lamp unless it turns once on its axis while performing its revolution. The same thing will be observed when a man walks around a tree, keeping his face constantly towards it. Since however the motion of the moon on its axis is uniform, while the motion in its orbit is unequal, the moon does in fact reveal to us a little sometimes of one side and sometimes of the other. Thus when the ball above mentioned is placed before the eye with its light side towards us, on carrying it round, if it is moved faster than it is turned on its axis,

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158. In what time does the moon turn on its axis? Illustrate by the motion of a ball around a lamp. Is the same side of the moon always turned exactly towards us?

a portion of the dark hemisphere is brought into view on one side; or if it is moved forward slower than it is turned on its axis, a portion of the dark hemisphere comes into view on the other side.

159. These appearances are called the moon's *librations in longitude.* The moon has also a *libration in latitude*, so called, because in one part of her revolution, more of the region around one of the poles comes into view, and in another part of the revolution, more of the region around the other pole; which gives the appearance of a tilting motion to the moon's axis. This has nearly the same cause with that which occasions our change of seasons. The moon's axis being inclined to the plane of her orbit, and always remaining parallel to itself, the circle which divides the visible from the invisible part of the moon, will pass in such a way as to throw sometimes more of one pole into view, and sometimes more of the other, as would be the case with the earth if seen from the sun. (See Fig. 22.)

The moon exhibits another phenomenon of this kind called her *diurnal libration*, depending on the daily rotation of the spectator. She turns the same face towards the center of the earth only, whereas we view her from the surface. When she is on the meridian, we see her disk nearly as though we viewed it from the center of the earth, and hence in this situation it is subject to little change; but when near the horizon, our circle of vision takes in more of the upper limb than would be presented to a spectator at the center of the earth. Hence, from this cause, we see a portion of one limb while the moon is rising, which is gradually lost sight of, and we see a portion of the opposite limb as the moon declines to the west. It will be remarked that neither of the foregoing changes implies any actual motion in the moon, but that each arises from a change of position in the spectator.

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159. Explain the librations in longitude. Ditto in latitude Ditto the diurnal librations.

160. Since the succession of day and night depends on the revolution of a planet on its own axis, an inhabitant of the moon would have but one day and one night during the whole lunar month of $29\frac{1}{2}$ days. One of its days, therefore, is equal to nearly 15 of ours. So protracted an exposure to the sun's rays, especially in the equatorial regions of the moon, must occasion an excessive accumulation of heat; and so long an absence of the sun must occasion a corresponding degree of cold. Each day would be a wearisome summer; each night a severe winter.* A spectator on the side of the moon which is opposite to us would never see the earth; but one on the side next to us would see the earth presenting a gradual succession of changes during his long night of 360 hours. Soon after the earth's conjunction with the sun, he would have the light of the earth reflected to him, presenting at first a crescent, but enlarging as the earth approaches its opposition, to a great orb, 13 times as large as the full moon appears to us, and affording nearly 13 times as much light. Our seas, our plains, our mountains, our volcanoes, and our clouds, would produce very diversified appearances, as would the various parts of the earth brought successively into view by its diurnal rotation. The earth while in view to an inhabitant of the moon, would *remain immovably fixed in the same part of the heavens.* For being unconscious of his own motion around the earth, as we are of our motion around the sun, the earth would seem to revolve around his own planet from west to east, just as the moon appears to us to revolve about the earth; but, meanwhile, his rotation along with the moon on her axis, would cause the earth to have an apparent motion

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160. How many days would an inhabitant of the moon have in a lunar month? What vicissitudes of temperature would occur in a single day? Would a spectator on the side of the moon opposite to us, ever see the earth? How would the earth appear to a spectator on the side of the moon next to us?

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* Francœur, Uranog. p. 91.

westward at the same rate. The two motions, therefore, would exactly balance each other, and the earth would appear all the while at rest.

161. We have thus far contemplated the revolution of the moon around the earth as though the earth were at rest. But, in order to have just ideas respecting the moon's motions, we must recollect that the moon likewise revolves along with the earth around the sun. It is sometimes said that the earth *carries* the moon along with her in her annual revolution. This language may convey an erroneous idea; for the moon, as well as the earth, revolves around the sun under the influence of two forces, and would continue her motion around the sun were the earth removed out of the way. Indeed, the moon is attracted towards the sun $2\frac{1}{5}$ times more than towards the earth, and would abandon the earth were not the latter also carried along with her by the same forces. So far as the sun acts equally on both bodies, their motion with respect to each other would not be disturbed. Because the gravity of the moon towards the sun is found to be greater, at the conjunction, than her gravity towards the earth, some have apprehended that, if the doctrine of universal gravitation is true, the moon ought necessarily to abandon the earth. In order to understand the reason why it does not do thus, we must reflect, that when a body is revolving in its orbit under the action of the projectile force and gravity, whatever diminishes the force of gravity while that of projection remains the same, causes the body to approach nearer to the tangent of her orbit, and of course to recede from the center; and whatever increases the amount of gravity carries the body towards the center.

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161. Can it be said that the earth carries the moon around the sun? How much more is the moon attracted towards the sun than towards the earth? Why does not the moon abandon the earth? When the sun acts equally on both bodies, does it disturb their relative places? How does the sun act upon these bodies at the conjunctions and oppositions?

Now, when the moon is in conjunction, her gravity towards the earth acts in opposition to that towards the sun, while her velocity remains too great to carry her, with what force remains, in a circle about the sun, and she therefore recedes from the sun, and commences her revolution around the earth. On arriving at the opposition, the gravity of the earth conspires with that of the sun, and the moon's projectile force being less than that required to make her revolve in a circular orbit, when attracted towards the sun by the sum of these forces, she accordingly begins to approach the sun and descends again to the conjunction.

162. The attraction of the sun, however, being every where greater than that of the earth, the actual path of the moon around the sun is every where concave towards the latter. Still the elliptical path of the moon around the earth, is to be conceived of in the same way as though both bodies were at rest with respect to the sun. Thus, while a steamboat is passing swiftly around an island, and a man is walking slowly around a post in the cabin, the line which he describes in space between the forward motion of the boat and his circular motion around the post, may be every where concave towards the island, while his path around the post will still be the same as though both were at rest. A nail in the rim of a coach wheel, will turn around the axis of the wheel, when the coach has a forward motion in the same manner as when the coach is at rest, although the line actually described by the nail will be the resultant of both motions, and very different from either.

163. We have hitherto regarded the moon as describing a great circle on the face of the sky, such being the

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162. How is the moon's path in space with respect to the sun? How is the elliptical path of the moon around the earth to be conceived of? How is this illustrated by the motions of a man in a steamboat? Also by the motions of a nail in the rim of a coach wheel?

visible orbit as seen by projection. But, on more exact investigation, it is found that her orbit is not a circle, and that her motions are subject to very numerous irregularities. These will be best understood in connection with the causes on which they depend. The law of universal gravitation has been applied with wonderful success to their investigation, and its results have conspired with those of long continued observation, to furnish the means of ascertaining with great exactness the place of the moon in the heavens at any given instant of time, past or future, and thus to enable astronomers to determine longitudes, to calculate eclipses, and to solve various other problems of the highest interest. A complete understanding of all the irregularities of the moon's motions, must be sought for in more extensive treatises of astronomy than the present; but some general acquaintance with the subject, clear and intelligible as far as it goes, may be acquired by first gaining a distinct idea of the mutual actions of the sun, the moon, and the earth.

164. *The irregularities of the moon's motions, are due chiefly to the disturbing influence of the sun, which operates in two ways; first, by acting unequally on the earth and moon, and, secondly, by acting obliquely on the moon, on account of the inclination of her orbit to the ecliptic.*

If the sun acted equally on the earth and moon, and always in parallel lines, this action would serve only to restrain them in their annual motions round the sun, and would not affect their actions on each other, or their motions about their common center of gravity. In that case, if they were allowed to fall directly towards the sun, they would fall equally, and their respective situations would not be affected by their descending equally towards it. We might then conceive them as in a plane, every part of which being equally acted on by

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163. Are the motions of the moon regular or irregular? By what general law are they explained?

the sun, the whole plane would descend towards the sun, but the respective motions of the earth and the moon in this plane, would be the same as if it were quiescent. Supposing then this plane and all in it, to have an annual motion imprinted on it, it would move regularly around the sun, while the earth and moon would move in it with respect to each other, as if the plane were at rest, without any irregularities. But because the moon is nearer the sun in one half of her orbit than the earth is, and in the other half of her orbit is at a greater distance than the earth from the sun, while the power of gravity is always greater at a less distance; it follows, that in one half of her orbit the moon is more attracted than the earth towards the sun, and in the other half less attracted than the earth. The *excess* of the attraction, in the first case, and the *defect* in the second, constitutes a disturbing force, to which we may add another, namely, that arising from the *oblique action* of the solar force, since this action is not directed in parallel lines, but in lines that meet in the center of the sun.

165. To see the effects of this process, let us suppose that the projectile motions of the earth and moon were destroyed, and that they were allowed to fall freely towards the sun. If the moon was in conjunction with the sun, or in that part of her orbit which is nearest to him, the moon would be more attracted than the earth. and fall with greater velocity towards the sun; so that the distance of the moon from the earth would be increased in the fall. If the moon was in opposition, or

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164. To what cause are the inequalities of the moon s motions chiefly due? If the sun acted equally on the earth and moon, and in parallel lines, would it disturb their motions? If allowed to fall towards the sun, how would they fall? How might we conceive them as situated in a plane? When is the moon more attracted than the earth? When is the earth more attracted than the moon? What constitutes the disturbing face.

165. Trace the effects of the sun, if the projectile force were destroyed, at conjunction, at opposition, and at quadrature.

in the part of her orbit which is farthest from the sun, she would be less attracted than the earth by the sun, and would fall with a less velocity towards the sun, and would be left behind ; so that the distance of the moon from the earth would be increased in this case also. If the moon was in one of the quarters, then the earth and moon being both attracted towards the center of the sun, they would both descend directly towards that center, and by approaching it, they would necessarily at the same time approach each other, and in this case their distance from each other would be diminished. Now whenever the action of the sun would increase their distance, if they were allowed to fall towards the sun, then the sun's action, by endeavouring to separate them diminishes their gravity to each other; whenever the sun's action would diminish the distance, then it increases their mutual gravitation. Hence, in the con junction and opposition, that is, *in the syzigies*, their gravity towards each other is diminished by the action of the sun, while in the quadratures it is increased. But it must be remembered that it is not the total action of the sun on them that disturbs their motions, but only that part of it which tends at one time to separate them, and at another time to bring them nearer together. The other and far greater part, has no other effect than to retain them in their annual course around the sun.

166. *The figure of the moon's orbit is an ellipse, having the earth in one of the foci.*

The greatest and least distances of the moon from the earth, are nearly 64 and 56, the radius of the earth being taken for unity. Hence, taking the arithmetical mean, we find that the mean distance of the moon from the

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166. What is the figure of the moon's orbit ? What are the greatest and least distances of the moon from the earth ? Define the terms perigee and apogee. What numbers express the greatest and least distance of the sun from the earth ? How does the eccentricity of the lunar orbit compare with that of the solar ?

earth is very nearly 60 times the radius of the earth. The point in the moon's orbit nearest the earth, is called her *perigee;* the point farthest from the earth, her *apogee.*

The greatest and least distances of the *sun* are respectively as the numbers 32.583, and 31.517. By comparing this ratio with that of the distances of the moon, it will be seen that the latter vary much more than the former, and consequently that the lunar orbit is much more eccentric than the solar. The eccentricity of the moon's orbit is in fact $\frac{1}{18}$ of its mean distance from the earth, while that of the earth is only $\frac{1}{59}$ of its mean distance from the sun,

167. *The moon's nodes constantly shift their positions in the ecliptic from east to west, at the rate of* 19° 35′ *per annum, returning to the same points in* 18.6 *years.*

Suppose the great circle of the ecliptic marked out on the face of the sky in a distinct line, and let us observe, at any given time, the exact point where the moon crosses this line, which we will suppose to be close to a certain star ; then, on its next return to that part of the heavens, we shall find that it crosses the ecliptic sensibly to the westward of that star, and so on, farther and farther to the westward every time it crosses the ecliptic at either node. This fact is expressed by saying that *the nodes retrograde on the ecliptic,* and that the line which joins them, or the line of the nodes, revolves from east to west.

168. The period occupied by the sun in passing from one of the moon's nodes until it comes round to the same node again, is called *the synodical revolution of the node.* This period is shorter than the sidereal year, being only about $346\frac{1}{2}$ days. For since the node shifts its

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167. How do the moon's nodes shift their position ? In what time do they make a complete revolutin in the ecliptic ? Explain what is meant by saying that the nodes retrogade.

place to the westward 19° 35′ per annum, the sun, in his annual revolution, comes to it so much before he completes his entire circuit; and since the sun moves about a degree a day, the synodical revolution of the node is 365—19=346, or more exactly, 346.619851. The time from one new moon, or from one full moon, to another, is 29.5305887 days. Now 19 synodical revolutions of the nodes contain very nearly 223 of these periods.

For $346.619851 \times 19 = 6585.78$.

And $29.5305887 \times 223 = 6585.32$.

Hence, if the sun and moon were to leave the moon's node together, after the sun had been round to the same node 19 times, the moon would have made very nearly 223 conjunctions with the sun, and would therefore, at the end of this period meet at the same node, to repeat the same circuit. And since eclipses of the sun and moon depend upon the relative position of the sun, the moon, and node, these phenomena are repeated in nearly the same order, in each of those periods. Hence, this period, consisting of about 18 years and 10 days, under the name of the *Saros*, was used by the Chaldeans and other ancient nations in predicting eclipses.

169. The *Metonic Cycle* is not the same with the Saros, but consists of 19 *tropical* years. During this period the moon makes very nearly 235 synodical revolutions, and hence the *new and full moons*, if reckoned by periods of 19 years, recur at the same dates. If, for example, a new moon fell on the fiftieth day of one cycle, it would also fall on the fiftieth day of each suc-

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168. What is meant by the synodical revolution of the node? How many new moons occur in 19 synodical revolutions of the node? Why was this period used in predicting eclipses? What was it called?

169. What is the period of the Metonic Cycle? How many conjunctions of the moon with the sun occur during this period? What use did the Athenians make of this lunar cycle?

ceeding cycle; and, since the regulation of games, feasts, and fasts, has been made very extensively according to new or full moons, hence this lunar cycle has been much used both in ancient and modern times. The Athenians adopted it 433 years before the Christian era, for the regulation of their calendar, and had it inscribed in letters of gold on the walls of the temple of Minerva. Hence the term *Golden Number*, which denotes the year of the lunar cycle.

170. *The line of the apsides of the moon's orbit revolves from west to east through her whole orbit in about nine years.*

If, in any revolution of the moon, we should accurately mark the place in the heavens where the moon comes to its perigee, (which would be known by the moon's apparent diameter being then greatest,) we should find, that at the next revolution, it would come to its perigee at a point a little farther eastward than before, and so on at every revolution, until, after nine years, it would come to its perigee at nearly the same point as at first. This fact is expressed by saying that the perigee and of course the apogee, revolves, and that the line which joins these two points, or the line of the apsides, also revolves.

171. The inequalities of the moon's motions are divided into periodical and secular. *Periodical* inequalities are those which are completed in comparatively short periods. *Secular* inequalities are those which are completed only in very long periods, such as centuries or ages. Hence the corresponding terms *periodical equations* and *secular equations*. As an example of a secular inequality, we may mention the *acceleration of the moon's mean motion*. It is discovered, that the moon actually revolves around the earth

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170. In what period does the line of the apsides revolve? Explain what is meant by this.

in less time now than she did in ancient times. The difference however is exceedingly small, being only about 10″ in a century, but increases from century to century as the square of the number of centuries. This remarkable fact was discovered by Dr. Halley.* In a lunar eclipse the moon's longitude differs from that of the sun, at the middle of the eclipse, by exactly 180°; and since the sun's longitude at any given time of the year is known, if we can learn the day and hour when an eclipse occurs, we shall of course know the longitude of the sun and moon. Now in the year 721 before the Christian era, on a specified day and hour, Ptolemy records a lunar eclipse to have happened, and to have been observed by the Chaldeans. The moon's longitude, therefore, for that time is known; and as we know the mean motions of the moon at present, starting from that epoch, and computing, as may easily be done, the place which the moon ought to occupy at present at any given time, she is found to be actually nearly a degree and a half in advance of that place. Moreover, the same conclusion is derived from a comparison of the Chaldean observations with those made by an Arabian astronomer of the tenth century.

This phenomenon at first led astronomers to apprehend that the moon encountered a resisting medium, which, by destroying at every revolution a small portion of her projectile force, would have the effect to bring her nearer and nearer to the earth and thus to augment her velocity. But in 1786, La Place demonstrated that

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171. How are the inequalities of the moon's motions divided? What are periodical inequalities? What are secular inequalities? Give an example of a secular inequality. How is it known that the moon's motions are accelerated? What is the amount of the acceleration per century? Will they always continue to be accelerated?

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* Astronomer Royal of Great Britain, and cotemporary with Sir Isaac Newton.

this acceleration is one of the legitimate effects of the sun's disturbing force, and is so connected with changes in the eccentricity of the earth's orbit, that the moon will continue to be accelerated while that eccentricity diminishes, but when the eccentricity has reached its minimum (as it will do after many ages) and begins to increase, then the moon's motion will begin to be retarded, and thus her motions will oscillate forever about a mean value.

CHAPTER V.

OF ECLIPSES.

172. An *Eclipse of the moon* happens when the moon in its revolution around the earth, falls into the earth's shadow. An *Eclipse of the sun* happens when the moon coming between the earth and the sun, covers either a part or the whole of the solar disk.

The earth and the moon being both opake globular bodies exposed to the sun's light, they cast shadows opposite to the sun like any other bodies on which the sun shines. Were the sun of the same size with the earth and the moon, then the lines drawn touching the surface of the sun, and the surface of the earth or moon (which lines form the boundaries of the shadow) would be parallel to each other, and the shadow would be a cylinder infinite in length; and were the sun less than the earth or the moon, the shadow would be an increasing cone, its narrower end resting on the earth; but as

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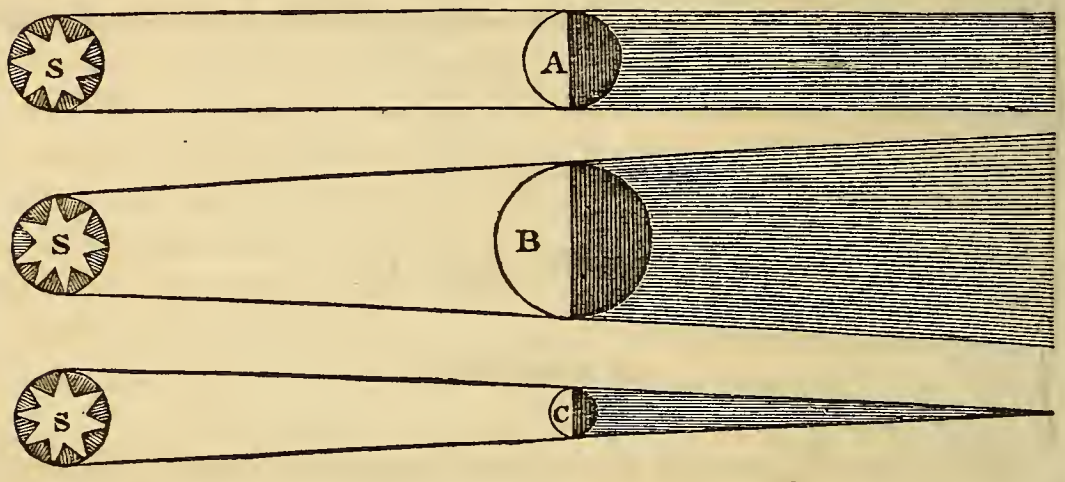
172. When does an eclipse of the moon happen? When does an eclipse of the sun happen? Were the sun of the same size with the earth and moon, how would their shadows be? How if less than these bodies? How are they in fact? Explain by figure 32

the sun is vastly greater than either of these bodies, the shadow of each is a cone, whose base rests on the body itself, and which comes to a point or vertex at a certain distance behind the body. These several cases are represented in the following diagrams.

Fig. 32.



173. It is found by calculation, that the length of the moon's shadow is, on an average, just about sufficient to reach to the earth, but the moon is sometimes farther from the earth than at others. (Art. 166.) When she is nearer than usual, the shadow reaches considerably beyond the surface of the earth. Also the moon as well as the earth, is at different distances from the sun at different times, and its shadow is longest when it is farthest from the sun. Now when both these circumstances conspire, that is, when the moon is in her perigee and in her aphelion, her shadow extends nearly 15000 miles beyond the center of the earth, and covers a space

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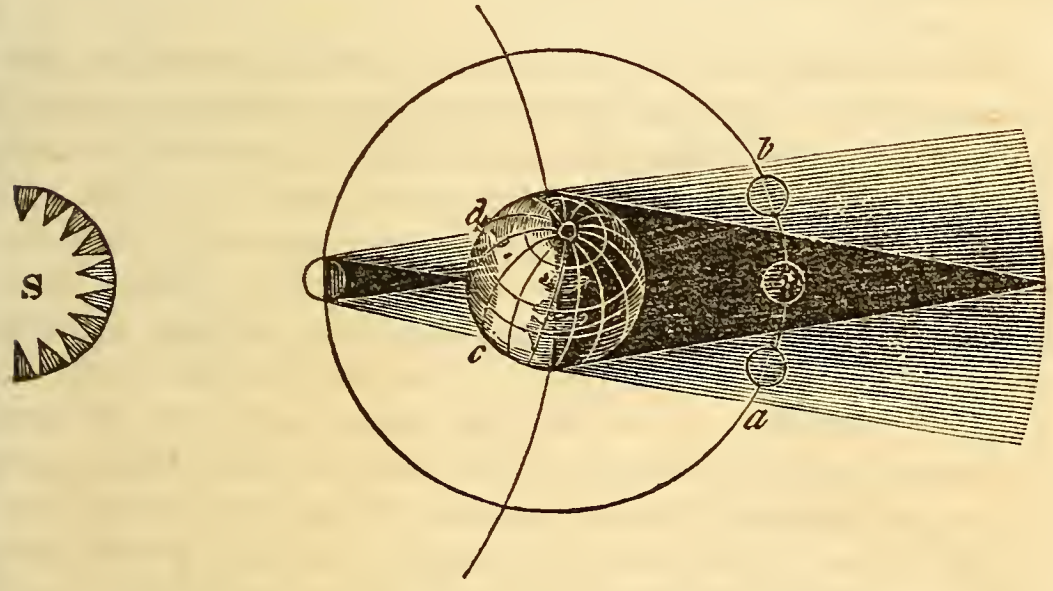
173. How does the moon's shadow compare with her distance from the earth? When does her shadow extend farthest beyond the center of the earth? What is the greatest breadth of her shadow where it falls on the surface of the earth? What is the length of the earth's shadow? When only can an eclipse of the sun take place? When only can an eclipse of the moon occur? Explain from figure 33. What is the moon's Penumbra?

on the surface of the earth 170 miles broad. The earth's shadow is towards a million of miles in length, and more than three and a half times as long as the distance from the earth to the moon; and it is also at the distance of the moon three times as broad as the moon itself. An eclipse of the sun can take place only at new moon, when the sun and moon meet in the same part of the heavens, for then only can the moon come between us and the sun; and an eclipse of the moon can occur only when the sun and moon are in opposite parts of the heavens, or at full moon, for then only can the moon fall into the shadow of the earth.

The nature of eclipses will be clearly understood from the following representation. This figure exhibits the

Fig. 33.



relative position of the sun, the earth, and the moon, both in a solar and in a lunar eclipse. It is evident from the figure, that if a spectator were situated where the moon's shadow strikes the earth, the moon would cut off from him the view of the sun, or the sun would be totally eclipsed. Or, if he were within a certain distance of the shadow on either side, the moon would be partly between him and the sun, and would intercept from him more or less of the sun's light, according as he was nearer to the shadow or farther from it. If he were at *c*, or *a*, he would just see the moon entering upon the

sun's disk; if he were nearer the shadow than either of these points, he would have a portion of the sun's light cut off from his view, and the moment he entered the shadow itself, he would lose sight of the sun. To all places between *c* or *d* and the shadow, the sun would cast a partial shadow of the moon, growing deeper and deeper as it approached the true shadow. This partial shadow is called the moon's *Penumbra*. In like manner, as the moon approaches the earth's shadow in a lunar eclipse, as soon as she arrives at *a*, the earth begins to intercept from her a portion of the sun's light, or she falls into the earth's penumbra. She continues to lose more and more of the sun's light as she draws near to the shadow, and hence her disk becomes gradually obscured, until it enters the shadow, where the sun's light is entirely lost.

174. As the sun and earth are both situated in the plane of the ecliptic, if the moon also revolved around the earth in this plane, we should have a solar eclipse at every new moon, and a lunar eclipse at every full moon; for in the former case the moon would come directly between us and the sun, and in the latter case, the earth would come directly between the sun and the moon. But the moon's path is inclined to the ecliptic about 5°, and the center of the moon may be all this distance from the center of the sun, at new moon, and the same distance from the center of the earth's shadow at full moon. It is true the moon extends across her path, one half her breadth lying on each side of it, and the sun likewise reaches from the ecliptic a distance equal to half his breadth. But these luminaries together make but little more than a degree, and consequently their two semi-diameters would occupy only

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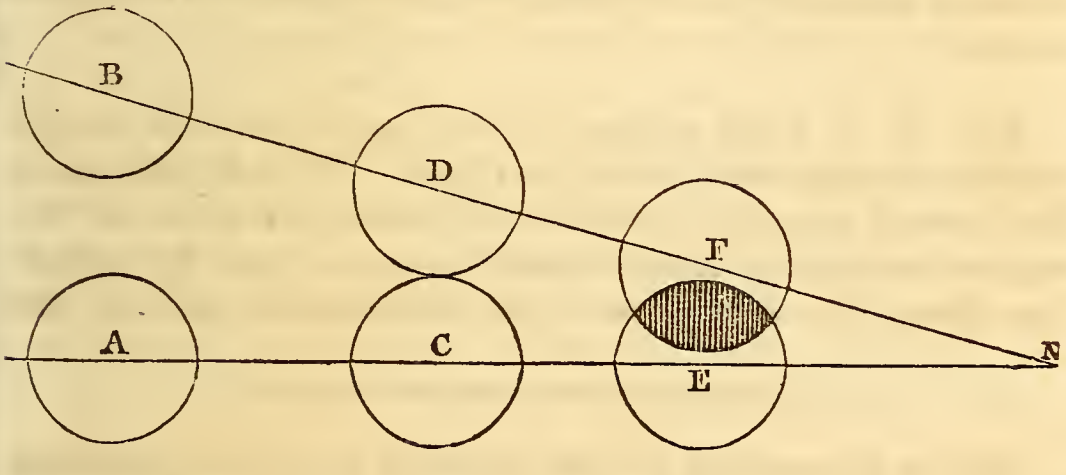
174. Why do we not have a solar eclipse every new moon, and a lunar eclipse every full moon? Explain how eclipses occur only when the sun is near one of the moon's nodes, by figure 34.

about half a degree of the five degrees from one orbit to the other. Also the earth's shadow where the moon crosses it extends from the ecliptic less than three fourths of a degree, so that the semi-diameter of the moon and of the earth's shadow, would together reach but little way across the space that may in certain cases separate the two luminaries from each other when they are in opposition. Thus suppose we could take hold of the circle in the figure that represents the moon's orbit, (Fig. 31,) and lift the moon up five degrees above the plane of the paper, it is evident that the moon as seen from the earth, would appear in the heavens five degreess above the sun, and of course would cut off none of his light, and that the moon at the full would pass the shadow of the earth five degrees below it, and would suffer no eclipse. But in the course of the sun's apparent revolution around the earth once a year, he is successively in every part of the ecliptic; consequently, the conjunctions and oppositions of the sun and moon may occur at any part of the ecliptic, and of course at the two points where the moon's orbit crosses the ecliptic, that is, at the nodes, for the sun must necessarily come to each of these nodes once a year. If then the moon overtakes the sun just as she is crossing his path,

Fig. 34.



she will hide more or less of his disk from us. Since, also, the earth's shadow is always directly opposite to the sun, if the sun is at one of the nodes, the shadow

must extend in the direction of the other node, so as to lie directly across the moon's path, and if the moon overtakes it there, she will pass through it and be eclipsed. Thus in figure 34, let BN represent the sun's path, and AN the moon's, N being the place of the node; then it is evident that if the two luminaries at new moon be so far from the node, that the distance between their centers is greater than their semi-diameters, no eclipse can happen; but if that distance is less than this sum as at E, F, then an eclipse will take place, but if the position be as at C, D, the two bodies will just touch one another. If A denote the earth's shadow instead of the sun, the same illustration will apply to an eclipse of the moon.

175. Since bodies are defined to be in conjunction when they are in the same part of the heavens, and to be in opposition when they are in opposite parts of the heavens, it may not appear how the sun and moon can be in conjunction as at A and B, when they are still at some distance from each other. But it must be recollected that bodies are in conjunction when they have the same longitude, in which case they are both situated in the same great circle perpendicular to the ecliptic, that is, in the same secondary to the ecliptic. One of the bodies may be much farther from the ecliptic than the other; still, if the same secondary to the ecliptic passes through them both, they will be in conjunction or opposition.

176. In a total eclipse of the moon, its disk is still visible, shining with a dull red light. This light cannot be derived directly from the sun, since the view of the sun is completely hidden from the moon; nor by reflexion from the earth, since the illuminated side of the

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175. Is it necessary for two bodies to be precisely together in order to be in conjunction?

176. Why is the disk of the moon still visible in a total eclipse of the moon?

earth is wholly turned from the moon; but it is owing to refraction from the earth's atmosphere, by which a few scattered rays of the sun are bent round into the earth's shadow and conveyed to the moon, sufficient in number to afford the feeble light in question.

177. It is impossible fully to understand the *method of calculating eclipses*, without a knowledge of trigonometry; still it is not difficult to form some general notion of the process. It may be readily conceived that, by long continued observations on the sun and moon, the exact places which they will occupy in the heavens at any future times, may be forseen and laid down in tables of the sun and moon's motions; that we may thus ascertain by inspecting the tables the exact instant when these two bodies will appear together in the heavens, or be in conjunction, and when they will be 180° apart, or in opposition. Moreover, since the exact place of the moon's node among the stars at any particular time is known to astronomers, it cannot be difficult to determine when the new or full moon occurs in the same part of the heavens as that where the node is projected as seen from the earth. In short, as astronomers can easily determine what will be the relative position of the sun, the moon, and the moon's nodes for any given time, they can tell when these luminaries will meet so near the node as to produce an eclipse of the sun, or when they will be in opposition so near the node as to produce an eclipse of the moon.

178. Let us endeavor to form a just conception of the manner in which these three bodies, the sun, the earth, and the moon, are situated with respect to each other at the time of a solar eclipse. First, suppose the conjunction to take place at the node. Then the straight line which connects the center of the sun and the earth, also passes

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177. What science must be known in order fully to understand the mode of calculating eclipses? Explain the general principles of the calculation.

through the center of the moon, and coincides with the axis of its shadow; and, since the earth is bisected by the plane of the ecliptic, the shadow would traverse the earth in the direction of the terrestrial ecliptic, from west to east, passing over the middle regions of the earth. Here the diurnal motion of the earth being in the same direction with the shadow, but with a less velocity, the shadow will appear to move with a speed equal only to the difference between the two. Secondly, suppose the moon is on the north side of the ecliptic at the time of conjunction, and moving towards her descending node, and that the conjunction takes place as far from the node as an eclipse can happen. The shadow will not fall in the plane of the ecliptic, but a little northward of it, so as just to graze the earth near the pole of the ecliptic. The nearer the conjunction comes to the node, the farther the shadow will fall from the pole of the ecliptic towards the equatorial regions.

179. The leading particulars respecting an ECLIPSE OF THE SUN, are ascertained very nearly like those of a lunar eclipse. The shadow of the moon travels over a portion of the earth, as the shadow of a small cloud, seen from an eminence in a clear day, rides along over hills and plains. Let us imagine ourselves standing on the moon; then we shall see the earth partially eclipsed by the shadow of the moon, in the same manner as we now see the moon eclipsed by the earth's shadow.

But, although the general characters of a solar eclipse might be investigated on these principles, so far as respects the earth at large, yet as the appearances of the same eclipse of the sun are very different at different places on the earth's surface, it is necessary to calculate

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178. Explain the relative position of the sun, the earth, and the moon, in a solar eclipse. Explain the circumstances when the conjunction takes place at the node, and when it occurs at a distance from the node.

its peculiar aspects for each place separately, a circumstance which makes the calculation of a solar eclipse much more complicated and tedious than of an eclipse of the moon. The moon, when she enters the shadow of the earth, is deprived of the light of the part immersed, and that part appears black alike to all places where the moon is above the horizon. But it is not so with a solar eclipse. We do not see this by the shadow cast on the earth, as we should do if we stood on the moon, but by the interposition of the moon between us and the sun; and the sun may be hidden from one observer while he is in full view of another only a few miles distant. Thus, a small insulated cloud sailing in a clear sky, will, for a few moments, hide the sun from us, and from a certain space near us, while all the region around is illuminated.

We have compared the motion of the moon's shadow over the surface of the earth to that of a cloud; but its *velocity* is incomparably greater. The mean motion of the moon around the earth is about 33′ per hour; but 33′ of the moon's orbit is 2280 miles, and the shadow moves of course at the same rate, or 2280 miles per hour, traversing the entire disk of the earth in less than four hours.

180. The diameter of the moon's shadow where it eclipses the earth can never exceed 170 miles, and commonly falls much short of that; and the greatest portion of the earth's surface ever covered by the moon's penumbra is about 4393 miles.

181. The apparent diameter of the moon is sometimes larger than that of the sun, sometimes smaller, and

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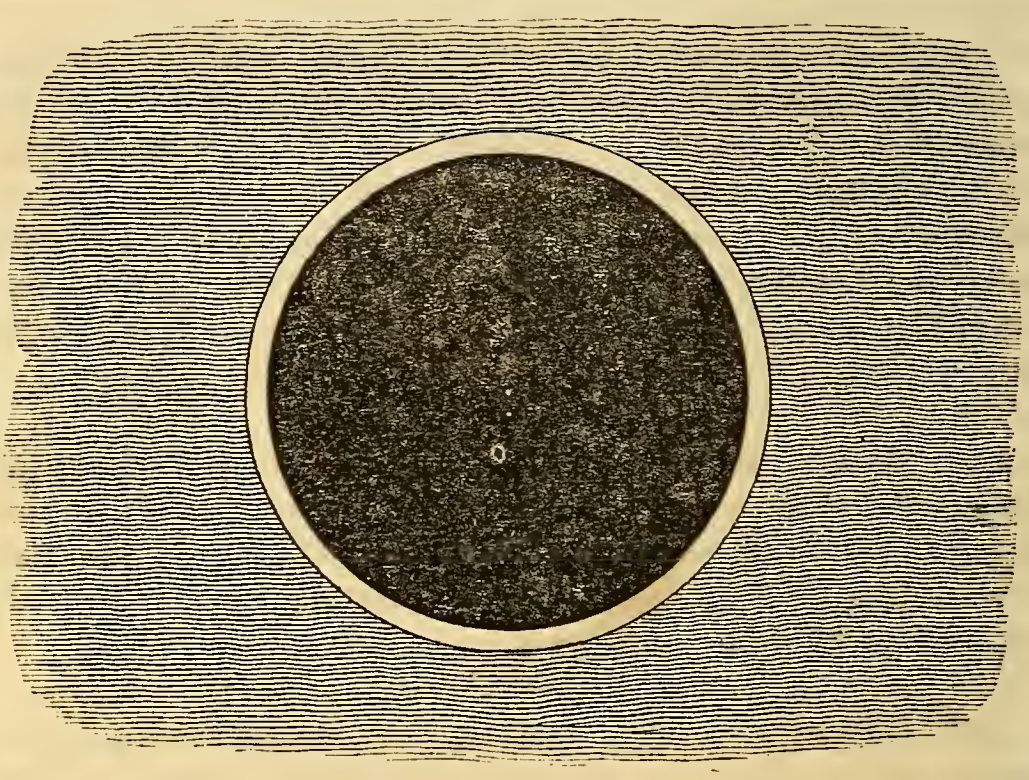
179. How are the leading particulars of an eclipse of the sun ascertained? How illustrated by the motion of a cloud? In what respects does the calculation of a solar differ from that of a lunar eclipse? How does the shadow of the moon compare with that of a cloud in velocity?

sometimes exactly equal to it. Suppose an observer placed on the right line which joins the centers of the sun and moon; if the apparent diameter of the moon is greater than that of the sun, the eclipse will be total. If the two diameters are equal, the moon's shadow just reaches the earth, and the sun is hidden but for a moment from the view of spectators situated in the line which the vertex of the shadow describes on the surface of the earth. But if, as happens when the moon comes to her conjunction in that part of her orbit which is towards her apogee, the moon's diameter is less than the sun's, then the observer will see a ring of the sun encircling the moon, constituting an *Annular Eclipse*, as in figure 35.

Fig. 35.



180. What cannot the diameter of the moon's shadow where it eclipses the earth, exceed? What is the greatest portion of the earth's surface ever covered by the moon's penumbra?

181. How does the moon's apparent diameter compare with the sun's? When will the eclipse be total, and when annular?

182. Eclipses of the sun are modified by the elevation of the moon above the horizon, since its apparent diameter is augmented as its altitude is increased. This effect, combined with that of parallax, may so increase or diminish the apparent distance between the centers of the sun and moon, that from this cause alone, of two observers at a distance from each other, one might see an eclipse which was not visible to the other. If the horizontal diameter of the moon differs but little from the apparent diameter of the sun, the case might occur where the eclipse would be annular over the places where it was observed morning and evening, but total where it was observed at mid-day.

The earth in its diurnal revolution and the moon's shadow both move from west to east, but the shadow moves faster than the earth; hence the moon overtakes the sun on its western limb and crosses it from west to east. The excess of the apparent diameter of the moon above that of the sun in a total eclipse is so small, that total darkness seldom continues longer than four minutes, and can never continue so long as eight minuutes. An annular eclipse may last 12m. 24s.

183. Eclipses of the sun are more frequent than those of the moon. Yet lunar eclipses being visible to every part of the terrestrial hemisphere opposite to the sun, while those of the sun are visible only to the small portion of the hemisphere on which the moon's shadow falls, it happens that for any particular place on the earth, lunar eclipses are more frequently visible than solar. In any year, the number of eclipses of both lu-

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182. How are eclipses of the sun modified by the elevation of the moon above the horizon? How might the same eclipse appear total to one observer and annular to another? How long can total darkness continue in a solar eclipse? How long may an annular eclipse last?

183. Which are most frequent, solar or lunar eclipses? Why does an eclipse of the moon sometimes happen at the next full moon after an eclipse of the sun?

minaries cannot be less than two nor more than seven: the most usual number is four, and it is very rare to have more than six. A total eclipse of the moon frequently happens at the next full moon after an eclipse of the sun. For since, in an eclipse of the sun, the sun is at or near one of the moon's nodes, the earth's shadow must be at or near the other node, and may not have passed far from the node before the moon overtakes it.

184. In total eclipses of the sun, there has sometimes been observed a remarkable radiation of light from the margin of the sun. This has been ascribed to an illumination of the solar atmosphere, but it is with more probability owing to the zodiacal light, which at that time is projected around the sun, and which is of such dimensions as to extend far beyond the solar orb.*

A total eclipse of the sun is one of the most sublime and impressive phenomena of nature. Among barbarous tribes it is ever contemplated with fear and astonishment, while among cultivated nations it is recognized, from the exactness with which the time of occurrence and the various appearances answer to the prediction, as affording one of the proudest triumphs of astronomy. By astronomers themselves it is of course viewed with the highest interest, not only as verifying their calculations, but as contributing to establish beyond all doubt the certainty of those grand laws, the truth of which is involved in the result. During the eclipse of June, 1806, which was one of the most remarkable on record, the time of total darkness, as seen by the author of this work, was about mid-day. The sky was entirely cloud-

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184. How is the radiation of light around the margin of the sun in a total eclipse of the sun, accounted for? How have eclipses of the sun been regarded among barbarous tribes? How among civilized nations? How by astronomers? Give some account of the great eclipse of 1806.

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* See an excellent description and delineation of this appearance as it was exhibited in the eclipse of 1806, in the Transactions of the Albany Institute, by the late Chancellor De Witt.

less, but as the period of total obscuration approached, a gloom pervaded all nature. When the sun was wholly lost sight of, planets and stars came into view; a fearful pall hung upon the sky, unlike both to night and to twilight; and, the temperature of the air rapidly declining, a sudden chill came over the earth. Even the animal tribes exhibited tokens of fear and agitation.

185. The word *Eclipse* is derived from a Greek word, (εκλειψις,) which signifies to fail, to faint, or swoon away, since the moon at the period of her greatest brightness falling into the shadow of the earth, was imagined by the ancients to sicken and swoon, as if she were going to die. By some very ancient nations she was supposed at such times to be in pain, and hence lunar eclipses were called the *labors of the* moon, (lunæ labores;) and, in order to relieve her fancied distress, they lifted torches high in the atmosphere, blew horns and trumpets, beat upon brazen vessels, and even, after the eclipse was over, they offered sacrifices to the moon. The opinion also extensively prevailed, that it was in the power of witches, by their spells and charms, not only to darken the moon, but to bring her down from her orbit, and to compel her to shed her baleful influences upon the earth. In a solar eclipse also, especially when total, the sun was supposed to turn away his face in abhorrence of some atrocious crime, that either had been perpetrated or was about to be perpetrated, and to threaten mankind with everlasting night, and the destruction of the world.

The Chinese, who from a very high period of antiquity have been great observers of eclipses, although they did not take much notice of those of the moon, regarded eclipses of the sun in general as unfortunate, but especially such as occurred on the first day of the year.

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185. From what is the word eclipse derived? What ideas had certain ancient nations respecting eclipses? With what ceremonies did they observe them? How were eclipses regarded among the Chinese?

These were thought to forbode the greatest calamities to the emperor, who on such occasions did not receive the usual compliments of the season. When an eclipse of the sun was expected from the predictions of their astronomers, they made great preparation at court for observing it; and as soon as it commenced, a blind man beat a drum and a great concourse assembled, and the Mandarins, or nobility, appeared in state.

186. From 1831 to 1838, was a period distinguished for great eclipses of the sun, in which time there were no less than five, of the most remarkable character. The next total eclipse of the sun, visible in the United States, will occur on the 7th of August, 1869.

CHAPTER VI.

OF LONGITUDE.—TIDES.

187. As eclipses of the sun afford one of the most approved methods of finding the longitude of places, our attention is naturally turned next towards that subject.

The ancients studied astronomy in order that they might read their destinies in the stars: the moderns that they may securely navigate the ocean. A large portion of the refined labors of modern astronomy, has been directed towards perfecting the astronomical tables with the view of finding the longitude at sea,—an object manifestly worthy of the highest efforts of science, considering the vast amount of property and of human life involved in navigation.

188. *The difference of longitude between two places, may be found by any method by which we can ascertain*

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186. What recent period has abounded with great eclipses of the sun? When will the next total eclipse of the sun occur?

187. For what purpose did the ancients study astronomy? For what purpose do the moderns study it?

the difference of their local times, at the same instant of absolute time.

As the earth turns on its axis from west to east, any place that lies eastward of another will come sooner under the sun, or will have the sun earlier on the meridian, and consequently, in respect to the hour of the day, will be in advance of the other at the rate of one hour for every 15°, or four minutes of time for each degree. Thus, to a place 15° east of Greenwich, it is 1 o'clock, P. M. when it is noon at Greenwich; and to a place 15° west of that meridian, it is 11 o'clock, A. M. at the same instant. Hence the difference of time at any two places, indicates their difference of longitude.

189. The easiest method of finding the longitude is by means of an accurate time piece, or *chronometer*. Let us set out from London with a chronometer accurately adjusted to Greenwich time, and travel eastward to a certain place, where the time is accurately kept, or may be ascertained by observation. We find, for example, that it is 1 o'clock by our chronometer, when it is 2 o'clock and 30 minutes at the place of observation. Hence the longitude is $15 \times 1.5 = 22\frac{1}{2}°$ E. Had we travelled westward until our chronometer was an hour and a half in advance of the time at the place of observation, (that is, so much later in the day,) our longitude would have been $22\frac{1}{2}°$ W. But it would not be necessary to repair to London in order to set our chronometer to Greenwich time. This might be done at any observatory, or any place whose longitude has been accu-

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188. How may the difference of longitude between two places be found? How many degrees of longitude correspond to one hour in time? How many minutes to one degree?

189. Explain the method of finding the longitude by the chronometer. To what time is it set? How do we ascertain the longitude of a place by it? Would it be necessary to repair to Greenwich to regulate our chronometer? What is said of the accuracy of some chronometers? Why is not this method adapted to general use?

rately determined. For example, the time at New York is 4h. 56m. 4s.5 behind that of Greenwich. If, therefore, we set our chronometer so much before the true time at New York, it will indicate the time at Greenwich. Moreover, on arriving at different places any where on the earth, whose longitude is accurately known, we may learn whether our chronometer keeps accurate time or not, and if not, the amount of its error. Chronometers have been constructed of such an astonishing degree of accuracy, as to deviate but a few seconds in a voyage from London to Baffin's Bay and back, during an absence of several years. But chronometers which are sufficiently accurate to be depended on for long voyages, are too expensive for general use, and the means of verifying their accuracy are not sufficiently easy. Moreover, chronometers, by being transported from one place to another, change their daily rate, or depart from that mean rate which they preserve at a fixed station. A chronometer, therefore, cannot be relied on for determining the longitudes of places where the greatest degree of accuracy is required, especially where the instrument is conveyed over land, although the uncertainty attendant on one instrument may be nearly obviated by employing several and taking their mean results.

190. *Eclipses of the sun and moon* are sometimes used for determining the longitude. The exact instant of immersion or of emersion, or any other definite moment of the eclipse which presents itself to two distant observers, affords the means of comparing their difference of time, and hence of determining their difference of longitude. Since the entrance of the moon into the earth's shadow, in a lunar eclipse, is seen at the same instant of absolute time at all places where the eclipse is visible, this observation would be a very suitable one for finding the longitude were it not that, on account of

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190. Explain how to find the longitude by eclipses of the sun and moon. What objections are there to this method, both in lunar and solar eclipses ?

the increasing darkness of the penumbra near the boundaries of the shadow, it is difficult to determine the precise instant when the moon enters the shadow. By taking observations on the immersions of known spots on the lunar disk, a mean result may be obtained which will give the longitude with tolerable accuracy. In an eclipse of the sun, the instants of immersion and emersion may be observed with greater accuracy, although, since these do not take place at the same instant of absolute time, the calculation of the longitude from observations on a solar eclipse are complicated and laborious.

191. *The lunar method of finding the longitude*, at sea, is in many respects preferable to every other. It consists in measuring (with a sextant) the angular distance between the moon and the sun, or between the moon and a star, and then turning to the Nautical Almanac,* and finding what time it was at Greenwich when that distance was the same. The moon moves so rapidly, that this distance will not be the same except at very nearly the same instant of absolute time. For example, at 9 o'clock, A. M., at a certain place, we find the angular distance of the moon and the sun to be 72°; and, on looking into the Nautical Almanac, we find that the time when this distance was the same for the meridian of Greenwich was 1 o'clock, P. M.; hence we infer that the longitude of the place is four hours, or 60° west.

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191. Explain the lunar method of finding the longitude. What measurements are made? How do we find the corresponding time at Greenwich?

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* The *Nautical Almanac*, is a book published annually by the British Board of Longitude, containing various tables and astronomical information for the use of navigators. The *American Almanac* also contains a variety of astronomical information, peculiarly interesting to the people of the United States, in connexion with a vast amount of statistical matter. It is well deserving of a place in the library of the student.

The Nautical Almanac contains the true angular distance of the moon from the sun, from the four large planets, (Venus, Mars, Jupiter, and Saturn,) and from nine bright fixed stars, for the beginning of every third hour of mean time for the meridian of Greenwich; and the mean time corresponding to any intermediate hour, may be found by proportional parts.*

192. It would be a very simple operation to determine the longitude by Lunar Distances, if the process as described in the preceding article were all that is necessary; but the various circumstances of parallax, refraction, and dip of the horizon, would differ more or less at the two places, even were the bodies, whose distances were taken, in view from both, which is not necessarily the case. The observations, therefore, require to be reduced to the center of the earth, being cleared of the effects of parallax and refraction. Hence, three observers are necessary in order to take a lunar distance in the most exact manner, viz. two to measure the altitudes of the two bodies respectively, at the same time that the third takes the angular distance between them. The altitudes of the two luminaries at the time of observation must be known, in order to estimate the effects of parallax and refraction.

193. Although the lunar method of finding the longitude at sea has many advantages over the other methods in use, yet it also has its disadvantages. One is, the great exactness requisite in observing the distance of the moon from the sun or star, as a small error in the distance makes a considerable error in the longitude. The moon moves at the rate of about a degree in two

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192. What difficulties are there in this method? Why are three observers necessary?

193. What are the objections to this method? What is the error of the best tables now in use?

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* See Bowditch's Navigator, Tenth Ed. p. 226.

hours, or one minute of space in two minutes of time. Therefore, if we make an error of one minute in observing the distance, we make an error of two minutes in time, or 30 miles of longitude at the equator. A single observation with the best sextant, may be liable to an error of more than half a minute; but the accuracy of the result may be much increased by a mean of several observations taken to the east and west of the moon. The imperfection of the lunar tables was until recently considered as an objection to this method. Until within a few years, the best lunar tables were frequently erroneous to the amount of one minute, occasioning an error of 30 miles. The error of the best tables now in use will rarely exceed 7 or 8 seconds.

TIDES.

194. The tides are an alternate rising and falling of the waters of the ocean, at regular intervals. They have a maximum and a minimum twice a day, twice a month, and twice a year. Of the daily tide, the maximum is called *High tide*, and the minimum *Low tide*. The maximum for the month is called *Spring tide*, and the minimum *Neap tide*. The rising of the tide is called *Flood* and its falling *Ebb* tide.

Similar tides, whether high or low, occur on opposite sides of the earth at once. Thus at the same time that it is high tide at any given place, it is also high tide on the inferior meridian, and the same is true of the low tides.

The interval between two successive high tides is 12h. 25m.; or, if the same tide be considered as returning to the meridian, after having gone around the globe,

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194. What are the tides? When have they a maximum and a minimum? Define the terms High and Low, Spring and Neap, Flood and Ebb tides. What two tides occur at the same time? What is the interval between two successive high tides? How much later is the tide of to-day than the same tide of yesterday? What is the average height of the tide for the whole globe? To what extreme height does it sometimes rise? Have inland lakes and seas any tides?

its return is about 50 minutes later than it occurred on the preceding day. In this respect, as well as in various others, it corresponds very nearly to the motions of the moon.

The average height for the whole globe is about $2\frac{1}{2}$ feet; or, if the earth were covered uniformly with a stratum of water, the difference between the two diameters of the oval would be 5 feet, or more exactly 5 feet and 8 inches; but its actual height at various places is very various, sometimes rising to 60 or 70 feet, and sometimes being scarcely perceptible. At the same place also, the phenomena of the tides are very different at different times.

Inland lakes and seas, even those of the largest class, as Lake Superior, or the Caspian, have no perceptible tide.

195. *Tides are caused by the unequal attraction of the sun and moon upon different parts of the earth.*

Suppose the projectile force by which the earth is carried forward in her orbit, to be suspended, and the earth to fall towards one of these bodies, the moon, for example, in consequence of their mutual attraction. Then, if all parts of the earth fell equally towards the moon, no derangement of its different parts would result, any more than of the particles of a drop of water in its descent to the ground. But if one part fell faster than another, the different portions would evidently be separated from each other. Now this is precisely what takes place with respect to the earth in its fall towards the moon. The portions of the earth in the hemisphere next to the moon, on account of being nearer to the center of attraction, fall faster than those in the opposite hemisphere, and consequently leave them behind. The solid earth, on account of its cohesion, cannot obey

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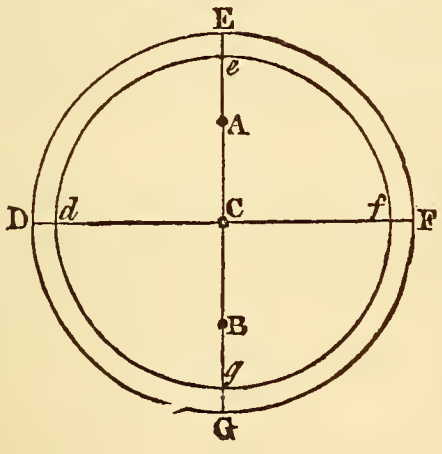
195. State the cause of the tides. What would be the consequence were the earth abandoned to the force exerted by the moon alone?

this impulse, since all its different portions constitute one mass, which is acted on in the same manner as though it were all collected in the center; but the waters on the surface, moving freely under this impulse, endeavor to desert the solid mass and fall towards the moon. For a similar reason the waters in the opposite hemisphere falling less towards the moon than the solid earth are left behind, or appear to rise from the center of the earth.

196. Let DEFG (Fig. 36,) represent the globe; and, for the sake of illustrating the principle, we will suppose the waters entirely to cover the globe at a uniform depth. Let *defg* represent the solid globe, and the cir-

Fig. 36.



cular ring exterior to it, the covering of waters. Let C be the center of gravity of the solid mass, A that of the hemisphere next to the moon, (for the center of gravity of a ring is within the ring,) and B that of the remoter hemisphere. Now the force of attraction exerted by the moon, acts in the same manner as though the solid mass were all concentrated in C, and the waters of each hemisphere at A and B respectively; and (the moon be-

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196. Explain the tides upon the doctrine of the center of gravity. Where would the tide-wave always be seen were it not for impediments? What are these?

ing supposed above E) it is evident that A will tend to leave C, and C to leave B behind. The same must evidently be true of the respective portions of matter, of which these points are the centers of gravity. The waters of the globe will thus be reduced to an oval shape, being elongated in the direction of that meridian which is under the moon, and flattened in the intermediate parts, and most of all at points ninety degrees distant from that meridian.

Were it not, therefore, for impediments which prevent the force from producing its full effects, we might expect to see the great *tide-wave*, as the elevated crest is called, always directly beneath the moon, attending it regularly around the globe. But the inertia of the waters prevents their instantly obeying the moon's attraction, and the friction of the waters on the bottom of the ocean, still farther retards its progress. It is not therefore until several hours (differing at different places) after the moon has passed the meridian of a place, that it is high tide at that place.

197. The *sun* has a similar action to the moon, but only *one third* as great. On account of the great mass of the sun compared with that of the moon, we might suppose that his action in raising the tides would be greater than that of the moon; but the nearness of the moon to the earth more than compensates for the sun's greater quantity of matter. Let us, however, form a just conception of the advantage which the moon derives from her proximity. It is not that her actual amount of attraction is thus rendered greater than that of the sun; but it is that her attraction for the *different parts* of the earth is very unequal, while that of the sun is nearly uniform. It is the *inequality* of this action, and not the absolute force, that produces the tides. The diameter of the earth is $\frac{1}{30}$ of the distance of the moon, while it is less than $\frac{1}{10000}$ of the distance of the sun.

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197. Explain the action of the sun in raising the tide? Why is its effect less than that of the moon?

198. Having now learned the general cause of the tides, we will next attend to the explanation of *particular phenomena.*

The *Spring tides*, or those which rise to an unusual height twice a month, are produced by the sun and moon's acting together; and the *Neap tides*, or those which are unusually low twice a month, are produced by the sun and moon's acting in opposition to each other. The Spring tides occur at the syzigies: the Neap tides at the quadratures. At the time of new moon, the sun and moon both being on the same side of the earth, and acting upon it in the same line, their actions conspire, and the sun may be considered as adding so much to the force of the moon. We have already explained how the moon contributes to raise a tide on the opposite side of the earth. But the sun as well as the moon raises its own tide-wave, which, at new moon, coincides with the lunar tide-wave. At full moon, also, the two luminaries conspire in the same way to raise the tide; for we must recollect that each body contributes to raise the tide on the opposite side of the earth as well as on the side nearest to it. At both the conjunctions and oppositions, therefore, that is, at the syzigies, we have unusually high tides. But here also the maximum effect is not at the moment of the syzigies, but 36 hours afterwards.

At the quadratures, the solar wave is lowest where the lunar wave is highest; hence the low tide produced by the sun is subtracted from high water and produces the Neap tides. Moreover, at the quadratures the solar wave is highest where the lunar wave is lowest, and hence is to be added to the height of low water at the time of Neap tides. Therefore the difference between high and low water is only about half as great at Neap tide as at Spring tide.

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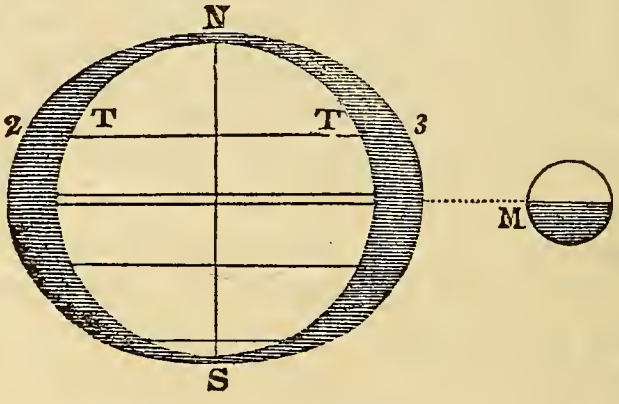
198. What is the cause of the Spring tides? Also of the Neap tides? How long after the syzigies does the highest tide occur?

199. The variations of distance in the sun are not great enough to influence the tides very materially, but the variations in the moon's distance have a striking effect. The tides which happen when the moon is in perigee, are considerably greater than when she is in apogee ; and if she happens to be in perigee at the time of the syzigies, the Spring tide is unusually high. When this happens at the equinoxes, the highest tides of the year are produced.

200. The *declinations of the sun and moon* have a considerable influence on the height of the tide. When the moon, for example, has no declination, or is in the

Fig. 37.



equator, as in figure 37,* the two tides will be exactly equal on opposite sides of the meridian in the same parallel. Thus a place in the parallel TT' will have

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199. How do the variations in the moon's distance from the earth affect the tides ? How are the tides when the moon is in perigee ? How when she in apogee ? When are the highest tides of the year produced ?

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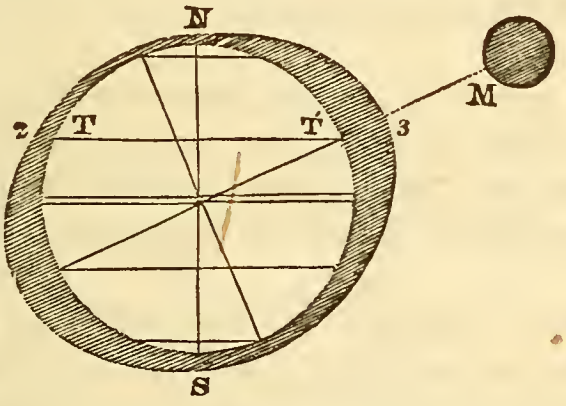
* Diagrams like these are apt to mislead the learner, by exhibiting the protuberance occasioned by the tides as much greater than the reality. We must recollect that it amounts, at the highest, to only a very few feet in eight thousand miles. Were the diagram, therefore, drawn in just proportions, the alteration of figure produced by the tides would be wholly insensible.

the height of one tide T2 and the other tide T′3. The tides are in this case greatest at the equator, and diminish gradually to the poles, where it will be low water during the whole day. When the moon is on the north side of the equator, as in figure 38, at her greatest northern declination, a place describing the parallel TT′ will have T′3 for the height of the

Fig. 38.



tide when the moon is on the superior meridian, and T2 for the height at the same time on the inferior meridian. Therefore, all places north of the equator will have the highest tide when the moon is above the horizon, and the lowest when she is below it; the difference of the tides diminishing towards the equator, where they are equal. In like manner, (the moon being still at M, Fig. 38, that is, having northern declination,) places south of the equator have the highest tides when the moon is below the horizon, and the lowest when she is above it. The circumstances are all reversed when the moon is south of the equator.

201. The motion of the tide-wave, it should be remarked, is not a *progressive* motion, but a mere undulation, and is to be carefully distinguished from the cur-

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200 Explain the effect of the declinations of the sun and moon upon the tides. How will the upper and lower tides correspond when the moon is in the equator? How when the moon is north of the equator? Explain by figures 37, 38.

rents to which it gives rise. If the ocean completely covered the earth, the sun and moon being in the equator, the tide-wave would travel at the same rate as the earth on its axis. Indeed, the correct way of conceiving of the tide-wave, is to consider the moon at rest, and the earth in its rotation from west to east, as bringing successive portions of water under the moon, which portions being elevated successively at the same rate as the earth revolves on its axis, have a relative motion westward in the same degree.

202. The tides of *rivers, narrow bays, and shores far from the main body of the ocean*, are not produced in those places by the direct action of the sun and moon, but are subordinate waves propagated from the great tide-wave.

Lines drawn through all the adjacent parts of any tract of water, which have high water at the same time, are called *cotidal lines*. We may, for instance, draw a line through all places in the Atlantic Ocean which have high tide in a given day at 1 o'clock, and another through all places which have high tide at 2 o'clock. The cotidal line for any hour may be considered as representing the summit or ridge of the tide-wave at that time; and could the spectator, detached from the earth, perceive the summit of the wave, he would see it traveling round the earth in the open ocean once in twenty-four hours, followed by another twelve hours distant, and both sending branches into rivers, bays, and other openings into the main land. These latter are called *Derivative* tides, while those raised directly by the action of the sun and moon, are called *Primitive* tides.

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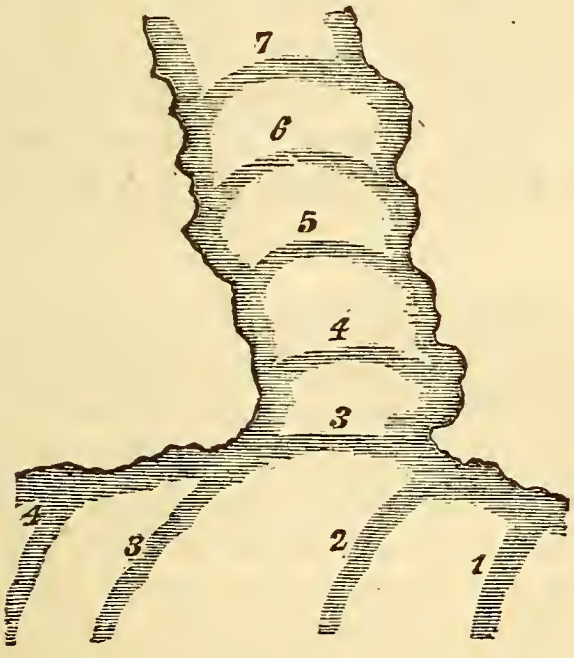
201. Is the motion of the tide-wave progressive? if the ocean completely covered the earth and the sun and moon were in the equator, how would the tide-wave travel? What is the most correct way of conceiving of the tide-wave?

202. How are the tides of rivers, &c. produced? Define cotidal lines. What does the cotidal line for any hour represent? Distinguish between Primitive and Derivative tides.

203. The velocity with which the wave moves, will depend on various circumstances, but principally on the depth, and probably on the regularity of the channel. If the depth be nearly uniform, the cotidal lines will be nearly straight and parallel. But if some parts of the channel are deep while others are shallow, the tide will be detained by the greater friction of the shallow places, and the cotidal lines will be irregular. The direction also of the derivative tide, may be totally different from that of the primative. Thus, (Fig. 39,) if the great

Fig. 39.



tide-wave, moving from east to west, be represented by the lines 1, 2, 3, 4, the derivative tide which is propagated up a river or bay, will be represented by the cotidal lines 3, 4, 5, 6, 7. Advancing faster in the channel than next the bank, the tides will lag behind towards the shores, and the cotidal lines will take the form of curves as represented in the diagram.

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203. On what will the velocity of the tide-wave depend? What circumstances will retard it? Explain figure 39.

204. On account of the retarding influence of shoals, and an uneven, indented coast, the tide-wave travels more slowly along the shores of an island than in the neighbouring sea, assuming convex figures at a little distance from the island and on opposite sides of it. These convex lines sometimes meet and become blended in such a manner as to create singular anomalies in a sea much broken by islands, as well as on coasts indented with numerous bays and rivers. Peculiar phenomena are also produced, when the tide flows in at opposite extremities of a reef or island, as into the two opposite ends of Long Island Sound. In certain cases a tide-wave is forced into a narrow arm of the sea, and produces very remarkable tides. The tides of the Bay of Fundy (the highest in the world) sometimes rise to the height of 60 or 70 feet; and the tides of the river Severn, near Bristol in England, rise to the height of 40 feet.

205. The *Unit of Altitude* of any place, is the height of the maximum tide after the syzigies, being usually about 36 hours after the new or full moon. But as the amount of this tide would be affected by the distance of the sun and moon from the earth, and by their declinations, these distances are taken at their mean value, and the luminaries are supposed to be in the equator; the observations being so reduced as to conform to these circumstances. The unit of altitude can be ascertained by observation only. The actual rise of the tide depends much on the strength and direction of the wind. When high winds conspire with a high flood tide, as is frequently the case near the equinoxes, the tide often

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204. How does the tide-wave travel along the shores of an island? How are the great tides of the Bay of Fundy accounted for? How high do they rise there, and at Bristol in England?

205. Define the unit of altitude. By what circumstances is the unit of altitude affected? How is it ascertained? State it for several places.

rises to a very unusual height. We subjoin from the American Almanac a few examples of the unit of altitude for different places.

	Feet.
Cumberland, head of the Bay of Fundy,	71
Boston,	$11\frac{1}{4}$
New Haven,	8
New York,	5
Charleston, S. C.,	6

206. The *Establishment* of any port is the mean interval between noon and the time of high water, on the day of new or full moon. As the interval for any given place is always nearly the same, it becomes a criterion of the retardation of the tides at that place. On account of the importance to navigation of a correct knowledge of the tides, the British Board of Admiralty, at the suggestion of the Royal Society, recently issued orders to their agents in various important naval stations, to have accurate observations made on the tides, with the view of ascertaining the establishment and various other particulars respecting each station; and the government of the United States is prosecuting similar investigations respecting our own ports.

207. According to Professor Whewell, the tides on the coast of North America are derived from the great tide-wave of the South Atlantic, which runs steadily northward along the coast to the mouth of the Bay of Fundy, where it meets the northern tide-wave flowing in the opposite direction. Hence he accounts for the high tides of the Bay of Fundy.

208. The largest *lakes* and *inland seas* have no perceptible tides. This is asserted by all writers respect-

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206. What is the establishment of a port? What efforts have been made to obtain accurate observations on the tides?

ing the Caspian and Euxine, and the same is found to be true of the largest of the North American lakes, Lake Superior.

Although these several tracts of water appear large when taken by themselves, yet they occupy but small portions of the surface of the globe, as will appear evident from the delineation of them on an artificial globe. Now we must recollect that the primitive tides are produced by the *unequal* action of the sun and moon upon the different parts of the earth; and that it is only at points whose distance from each other bears a considerable ratio to the whole distance of the sun or the moon, that the inequality of action becomes manifest. The space required is larger than either of these tracts of water. It is obvious also that they have no opportunity to be subject to a derivative tide.

209. To apply the theory of universal gravitation to all the varying circumstances that influence the tides, becomes a matter of such intricacy, that La Place pronounces "the problem of the tides" the most difficult problem of celestial mechanics.

210. The *Atmosphere* that envelops the earth, must evidently be subject to the action of the same forces as the covering of waters, and hence we might expect a rise and fall of the barometer, indicating an atmospheric tide corresponding to the tide of the ocean. La Place has calculated the amount of this aerial tide. It is too inconsiderable to be detected by changes in the barometer, unless by the most refined observations. Hence it is concluded, that the fluctuations produced by this cause are too slight to affect meteorological phenomena in any appreciable degree.

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207. How are the tides on the coast of North America derived?

208. Why have lakes and seas no tides?

209. What is said of the difficulty of applying the principle of universal gravitation to all the circumstances of the tides?

CHAPTER VII.

OF THE PLANETS—THE INFERIOR PLANETS, MERCURY AND VENUS.

211. The name planet signifies a *wanderer*,* and is applied to this class of bodies because they shift their positions in the heavens, whereas the fixed stars constantly maintain the same places with respect to each other. The planets known from a high antiquity, are Mercury, Venus, Earth, Mars, Jupiter, and Saturn. To these, in 1781, was added Uranus,† (or *Herschel*, as it is sometimes called from the name of its discoverer,) and, as late as the commencement of the present century, four more were added, namely, Ceres, Pallas, Juno, and Vesta. These bodies are designated by the following characters:

1. Mercury	☿	7. Ceres	⚳
2. Venus	♀	8. Pallas	⚴
3. Earth	⊕	9. Jupiter	♃
4. Mars	♂	10. Saturn	♄
5. Vesta	⚶	11. Uranus	♅
6. Juno	⚵		

The foregoing are called the *primary* planets. Several of these have one or more attendants, or satellites,

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210. Has the atmosphere any tide? Is it sufficient to influence meteorological phenomena?

211. Whence is the name planet derived? Which of the planets have been long known? Which have been added in modern times? Mark on paper or on the black board, the several characters by which the planets are designated. Distinguish between the primary and the secondary planets. What bodies have satellites? State the whole number of planets.

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* From the Greek πλανητης.

† From *Ουρανος*.

which revolve around them, as they revolve around the sun. The earth has one satellite, namely, the moon; Jupiter has four; Saturn, seven; and Uranus, six. These bodies also are planets, but in distinction from the others they are called *secondary* planets. Hence, the whole number of planets are 29, viz. 11 primary, and 18 secondary planets.

212. With the exception of the four new planets, these bodies have their orbits very nearly in the same plane, and are never seen far from the ecliptic. Mercury, whose orbit is most inclined of all, never departs farther from the ecliptic than about 7°, while most of the other planets pursue very nearly the same path with the earth, in their annual revolutions around the sun. The new planets, however, make wider excursions from the plane of the ecliptic, amounting, in the case of Pallas, to $34\frac{1}{2}°$.

213. Mercury and Venus are called *inferior* planets, because they have their orbits nearer to the sun than that of the earth; while all the others, being more distant from the sun than the earth, are called *superior* planets. The planets present great diversity among themselves in respect to distance from the sun, magnitude, time of revolution, and density. They differ also in regard to satellites, of which, as we have seen, three have respectively four, six, and seven, while more than half have none at all. It will aid the memory, and render our view of the planetary system more clear and comprehensive, if we classify, as far as possible, the various particulars comprehended under the foregoing heads.

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212. Near what great circle are the orbits of all the planets? How far does Pallas deviate from the ecliptic?

213. Why are Mercury and Venus called Inferior planets? Why are the other planets called superior? What diversities do the planets exhibit among themselves?

214. DISTANCES FROM THE SUN.

1. Mercury,	. .	37,000,000
2. Venus,	. .	68,000,000
3. Earth,	. .	95,000,000
4. Mars,	. .	142,000,000
5. Vesta,	. .	225,000,000
6. Juno,	. .	261,000,000
7. Ceres,	. .	
8. Pallas,	. .	
9. Jupiter,	. .	485,000,000
10. Saturn,	. .	890,000,000
11. Uranus,	. .	1800,000,000

The *dimensions* of the planetary system are seen from this table to be vast, comprehending a circular space thirty six hundred millions of miles in diameter. A railway car, travelling constantly at the rate of 20 miles an hour, would require more than 20,000 years to cross the orbit of Uranus.

It may aid the memory to remark, that in regard to the planets nearest the sun, the distances increase in an arithmetical ratio, while those most remote, increase in a geometrical ratio. Thus, if we add 30 to the distance of Mercury, it gives us nearly that of Venus; 30 more gives that of the Earth; while Saturn is nearly twice the distance of Jupiter, and Uranus twice the distance of Saturn. Between the orbits of Mars and Jupiter, a great chasm appeared, which broke the continuity of the series; but the discovery of the new planets has filled the void.

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214. State the distance of each of the planets from the sun. What is said of the dimensions of the planetary system? How do the distances of those planets which are nearest the sun increase? Also those which are more distant? How may the mean distances of the planets from the sun be determined? Give an example in computing the distance of Jupiter.

The mean distances of the planets from the sun, may be determined by means of Kepler's law, that the squares of the periodical times are as the cubes of the distances. Thus the earth's distance being previously ascertained by means of the sun's horizontal parallax, and the period of any other planet, as Jupiter, being learned from observation, we say as $\overline{365.256}^2 : \overline{4332.585}^{2*} :: 1^3 : 5.202^3$, which equals the cube of Jupiter's distance from the sun, and its root equals that distance itself.

215. MAGNITUDES.

	Diam. in Miles.	Mean apparent Diam.	Volume.
Mercury,	3140	6″.9	$\frac{1}{17}$
Venus,	7700	61″.9	$\frac{9}{10}$
Earth,	7912		1
Mars,	4200	6″.3	$\frac{1}{7}$
Ceres,	160	0″.5	
Jupiter,	89000	36″.7	1281
Saturn,	79000	16″.2	995
Uranus,	35000	4″.0	80

We remark here a great diversity in regard to magnitude, a diversity which does not appear to be subject to any definite law. While Venus, an inferior planet, is $\frac{9}{10}$ as large as the earth, Mars, a superior planet is only $\frac{1}{7}$, while Jupiter is 1281 times as large. Although several of the planets, when nearest to us, appear brilliant and large when compared with the fixed stars, yet the angle which they subtend is very small, that of Venus, the greatest of all, never exceeding about 1′, or more exactly 61″.9, and that of Jupiter being when greatest only about $\frac{3}{4}$ of a minute.

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215. State the diameter of each of the planets. What diversities occur in regard to their magnitudes? How great angles do Venus and Jupiter subtend?

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* This is the number of days in one revolution of Jupiter.

216. PERIODIC TIMES.

	Revolution in its orbit.			Mean daily motion.
Mercury,	3 months, or	88	days,	4° 5′ 32″.6
Venus,	7½ "	" 224	"	1° 36′ 7″.8
Earth,	1 year,	" 365	"	0° 59′ 8″.3
Mars,	2 years,	" 687	"	0° 31′ 26″.7
Ceres,	4 "	" 1681	"	0° 12′ 50″.9
Jupiter,	12 "	" 4332	"	0° 4′ 59″.3
Saturn,	29 "	" 10759	"	0° 2′ 0″.6
Uranus,	84 "	" 30686	"	0° 0′ 42″.4

From this view, it appears that the planets nearest the sun move most rapidly. Thus Mercury performs nearly 350 revolutions while Uranus performs one. This is evidently not owing merely to the greater dimensions of the orbit of Uranus, for the length of its orbit is not 50 times that of the orbit of Mercury, while the time employed in describing it is 350 times that of Mercury. Indeed this ought to follow from Kepler's law that the squares of the periodical times are as the *cubes* of the distances, from which it is manifest that the times of revolution increase faster than the dimensions of the orbit. Accordingly, the apparent progress of the most distant planets is exceedingly slow, the daily rate of Uranus being only 42″.4 per day ; so that for weeks and months, and even years, this planet but slightly changes its place among the stars.

THE INFERIOR PLANETS, MERCURY AND VENUS.

217. The inferior planets, Mercury and Venus, having their orbits so far within that of the earth, appear to us as attendants upon the sun. Mercury never appears farther from the sun than 29° (28° 48′) and seldom so

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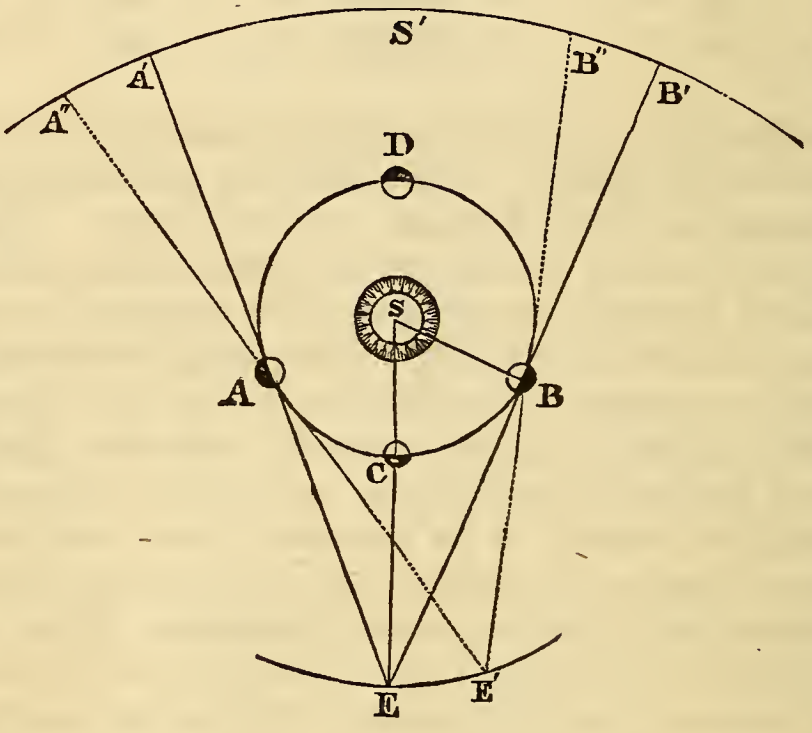
216. State the periodic time of each of the planets. Which planets move most rapidly ? How many revolutions does Mercury perform while Uranus performs one ? What is the daily rate of Uranus ?

far; and Venus never more than about 47° (47° 12′). Both planets, therefore, appear either in the west soon after sunset, or in the east a little before sunrise. In high latitudes, where the twilight is prolonged, Mercury can seldom be seen with the naked eye, and then only at the periods of its greatest elongation.* The reason of this will readily appear from the following diagram.

Fig. 40.



Let S (Fig. 40,) represent the sun, ADB the orbit of Mercury, and E the place of the Earth. Each of the planets is seen at its greatest elongation, when a line, EA or EB in the figure, is a tangent to its orbit. Then the sun being at S′ in the heavens, the planet will be

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217. What is Mercury's greatest elongation from the sun? What is Venus's? What is said respecting the difficulty of seeing Mercury? Explain by figure 40.

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* Copernicus is said to have lamented on his death-bed that he had never been able to obtain a sight of Mercury, and Delambre saw it but twice.

seen at A′ and B′, when at its greatest elongations, and will appear no further from the sun than the arc S′A′ or S′B′ respectively.

218. A planet is said to be in *Conjunction* with the sun, when it is seen in the same part of the heavens with the sun, or when it has the same longitude. Mercury and Venus have each two conjunctions, the inferior, and the superior. The *inferior conjunction* is its position when in conjunction on the same side of the sun with the earth, as at C in the figure: the *superior conjunction* is its position when on the side of the sun most distant from the earth, as at D.

219. The period occupied by a planet between two successive conjunctions with the earth, is called its *synodical revolution*. Both the planet and the earth being in motion, the time of the synodical revolution exceeds that of the sidereal revolution of Mercury or Venus; for when the planet comes round to the place where it before overtook the earth, it does not find the earth at that point, but far in advance of it. Thus, let Mercury come into inferior conjunction with the earth at C, (Fig. 40.) In about 88 days, the planet will come round to the same point again; but meanwhile the earth has moved forward through the arc EE′, and will continue to move while the planet is moving more rapidly to overtake her, the case being analogous to that of the hour and minute hand of a clock.

The synodical period of Mercury is 116, and of Venus 584 days.

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218. When is a planet said to be in conjunction with the sun? What conjunctions have the inferior planets?

219. Define the synodical revolution. How does this period compare with the sidereal revolution? Explain by figure 40. What is the synodical period of Mercury and Venus respectively?

220. *The motion of an inferior planet is direct in passing through its superior conjunction, and retrogade in passing through its inferior conjunction.* Thus Venus, while going from B through D to A, (Fig. 40,) moves in the order of the signs, or from west to east, and would appear to traverse the celestial vault B′S′A′ from right to left; but in passing from A through C to B, her course would be retrogade, returning on the same arc from left to right. *If the earth were at rest*, therefore, (and the sun, of course, at rest,) the inferior planets would appear to oscillate backwards and forwards across the sun. But, it must be recollected, that the earth is moving in the same direction with the planet, as respects the signs, but with a slower motion. This modifies the motions of the planet, accelerating it in the superior and retarding it in the inferior conjunctions. Thus in figure 40, Venus while moving through BDA would seem to move in the heavens from B′ to A′ were the earth at rest; but meanwhile the earth changes its position from E to E′ by which means the planet is not seen at A′ but at A″, being accelerated by the arc A′A″ in consequence of the earth's motion. On the other hand, when the planet is passing through its inferior conjunction ACB, it appears to move backwards in the heavens from A′ to B′ if the earth is at rest, but from A′ to B″ if the earth has in the mean time moved from E to E′ being retarded by the arc B′B″. Although the motions of the earth have the effect to accelerate the planet in the superior conjunction, and to retard it in the inferior, yet, on account of the greater distance, the apparent motion of the planet is much slower in the superior than in the inferior conjunction.

221. *When passing from the superior to the inferior conjunction, or from the inferior to the superior conjunc-*

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220. When is the motion of an inferior planet direct and when retrograde? Explain by figure 40. If the earth were at rest, how would the inferior planets appear to move? Show how the earth's motion modifies the apparent motions.

tion through the greatest elongations, the inferior planets are stationary.

If the earth were at rest, the stationary points would be at the greatest elongations as at A and B, for then the planet would be moving directly towards or from the earth, and would be seen for some time in the same place in the heavens; but the earth itself is moving nearly at right angles to the line of the planet's motion, that is, the line which is drawn from the earth to the planet through the point of greatest elongation; hence a direct motion is given to the planet by this cause. When the planet, however, has passed this line by its superior velocity, it soon overcomes this tendency of the earth to give it a relative motion eastward, and becomes retrograde as it approaches the inferior conjunction. Its stationary point obviously lies between its place of greatest elongation, and the place where its motion becomes retrograde. Mercury is stationary at an elongation of from 15° to 20° from the sun; and Venus at about 29°.

222. *Mercury and Venus exhibit to the telescope, phases similar to those of the moon.*

When on the side of their inferior conjunction, these planets appear horned, like the moon in her first and last quarters; and when on the side of their superior conjunctions they appear gibbous. At the moment of superior conjunction, the whole enlightened orb of the planet is turned towards the earth, and the appearance would be that of the full moon, but the planet is too near the sun to be commonly visible.

These different phases show these bodies are opake, and shine only as they reflect to us the light of the sun; and the same remark applies to all the planets.

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221. When are the inferior planets stationary? Why are they not stationary at the points of greatest elongation? At what elongation are Mercury and Venus stationary respectively?

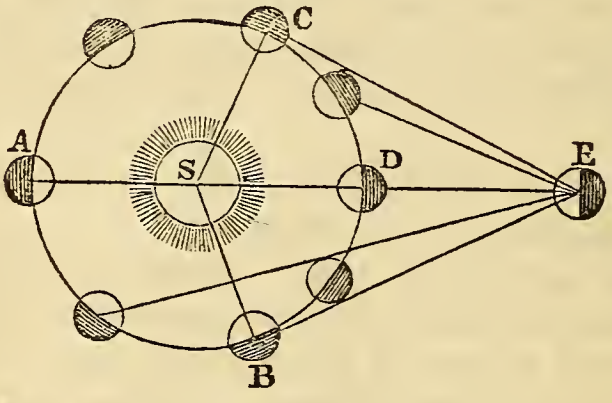
222. What phases do Mercury and Venus exhibit? Explain by figure 40. Whence do these bodies derive their light? Is the same true of the other planets?

223. *The orbit of Mercury is the most eccentric, and the most inclined of all the planets;* while that of Venus varies but little from a circle, and lies much nearer to the ecliptic.*

The eccentricity of the orbit of Mercury is nearly $\frac{1}{5}$ its semi-major axis, while that of Venus is only $\frac{1}{145}$; the inclination of Mercury's orbit is 7°, while that of Venus is less than $3\frac{1}{2}°$. Mercury, on account of his different distances from the earth, varies much in his apparent diameter, which is only 5″ in the apogee, but 12″ in the perigee. The inclination of his orbit to his equator being very great, the changes of his seasons must be proportionally great.

These different aspects of an inferior planet will be easily understood from Fig. 41, where the earth is at E,

Fig. 41.



and the planet is represented in various positions in its revolutions around the sun. When at A, in the superior conjunction, the whole enlightened disk is turned towards us; at D, in the inferior conjunction, the enlightened side is turned entirely from us; and at the quadratures B and C, half the disk is in view. Between A and B, and A and C, the planet is gibbous, like the moon in her second and third quarters; and between B

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223. What is said of the eccentricity and inclination of the orbit of Mercury? How does the apparent diameter of Mercury vary? How are his changes of seasons?

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* The new planets of course excepted.

and D, and C and D, the planet is horned, like the moon in her first and last quarters.

224. *An inferior planet is brightest at a certain point between its greatest elongation and inferior conjunction.*

Its maximum brilliancy would happen at the inferior conjunction, (being then nearest to us,) if it shined by its own light; but in that position its dark side is turned towards us. Still, its maximum cannot be when most of the illuminated side is towards us; for then, being at the superior conjunction, it is at its greatest distance from us. The maximum must therefore be somewhere between the two. Venus gives her greatest light when about 40° from the sun.

225. *Mercury and Venus oth revolve on their axes, in nearly the same time with the earth.*

The diurnal period of Mercury is 24h. 5m. 28s., and that of Venus 23h. 21m. 7s. The revolutions on their axes have been determined by means of some spot or mark seen by the telescope, as the revolution of the sun on his axis is ascertained by means of his spots.

226. Venus is regarded as the most beautiful of the planets, and is well known as the *morning and evening star.* The most ancient nations did not indeed recognize the evening and morning star as one and the same body, but supposed they were different planets, and accordingly gave them different names, calling the morning star Lucifer, and the evening star Hesperus. At her period of greatest splendor, Venus casts a shadow, and is sometimes visible in broad daylight. Her light is then estimated as equal to that of twenty stars of the first

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224. When is an inferior planet brightest? Why not when nearest to us? Why not when most of the illuminated side is turned towards us?

225. In what time do Mercury and Venus, respectively, revolve on their axes? How are these periods ascertained?

magnitude. At her period of greatest elongation, Venus is visible from three to four hours after the setting or before the rising of the sun.

227. *Every eight years, Venus forms her conjunctions with the sun in the same part of the heavens.*

For, since the synodical period of Venus is 584 days, and her sidereal period 224.7,

224.7 : 360° : : 584 : 935.6 = the arc of longitude described by Venus between the first and second conjunctions. Deducting 720°, or two entire circumferences the remainder, 215°.6, shows how far the place of the second conjunction is in advance of the first. Hence, in five synodical revolutions, or 2920 days, the same point must have advanced $215°.6 \times 5 = 1078°$, which is nearly three entire circumferences, so that at the end of five synodical revolutions, occupying 2920 days, or 8 years, the conjunction of Venus takes place nearly in the same place in the heavens as at first.

Whatever appearances of this planet, therefore, arise from its position with respect to the earth and the sun, they are repeated every eight years in nearly the same form.

TRANSITS OF THE INFERIOR PLANETS.

228. *The Transit of Mercury or Venus, is its passage across the sun's disk, as the moon passes over it in a solar eclipse.*

As a transit takes place only when the planet is in inferior conjunction, at which time her motion is retrograde, it is always from left to right, and the planet is seen projected on the solar disk in a black round spot.

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226. What erroneous notions had the ancients respecting the morning and evening star? What is said of the brilliancy of Venus at her greatest splendor? How long may Venus be in sight after sunset?

227. What happens to Venus every eight years?

Were the orbits of the inferior planets coincident with the plane of the earth's orbit, a transit would occur to some part of the earth at every inferior conjunction. But the orbit of Venus makes an angle of $3\frac{1}{2}°$ with the ecliptic, and Mercury an angle of 7°; and, moreover, the apparent diameter of each of these bodies is very small, both of which circumstances conspire to render a transit a comparatively rare occurrence, since it can happen only when the sun, at the time of an inferior conjunction, chances to be at or extremely near the planet's node. The nodes of Mercury lie in longitude 46° and 226°, points which the sun passes through in May and November. It is only in these months, therefore, that transits of Mercury can occur. For a similar reason, those of Venus occur only in June and December. Since, however, the nodes of both planets have a small retrograde motion, the months in which transits occur will change in the course of ages

229. Transits of Mercury occur more frequently than those of Venus. The periodic times of Mercury and the earth are so adjusted to each other, that Mercury performs nearly 29 revolutions while the earth performs 7. If, therefore, the two bodies meet at the node in any given year, seven years afterwards they will meet nearly at the same node, and a transit may take place, accordingly, at intervals of 7 years. But 54 revolutions of Mercury correspond still nearer to 13 revolutions of the

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228. What is meant by the transit of Mercury or Venus? When only can a transit take place? What angles do the orbits of Venus and Mercury respectively make with the ecliptic? In what months does the sun pass through the nodes of each of these planets?

229. Which planet has the most frequent transits? What is the shortest interval of the transits of Mercury? What are the longer intervals? When will the next occur? What are intervals of the transits of Venus? When was the last transit of Venus, and when will the next occur?

earth, and therefore a transit is still more probable after intervals of 13 years. At intervals of 33 years, transits of Mercury are exceedingly probable, because in that time Mercury makes almost exactly 137 revolutions. Intermediate transits however may occur at the other node, these intervals having reference merely to the same node. Thus transits of Mercury happened at the ascending node in 1815, and 1822, at intervals of 7 years; and at the descending node in 1832, which will return in 1845, after an interval of 13 years. Transits of Venus are much more unfrequent than those of Mercury. Eight revolutions of the earth are completed in nearly the same time as thirteen revolutions of Venus, and hence two transits of Venus may occur at an interval of 8 years, as was the case at the last return of this phenomenon, one transit having occurred in 1761, and another in 1769. But if a transit does not happen after 8 years, it will not happen, at the same node, until an interval of 235 years; but intermediate transits may occur at the other node. The next transit of Venus will take place in 1874, being 235 years after the first that was ever observed, which occurred in the year 1639. In the mean time, as already mentioned, two transits have occurred at the other node, at intervals of 8 years.

230. The great interest attached by astronomers to a transit of Venus, arises from its furnishing the most accurate means in our power of determining the *sun's horizontal parallax*—an element of great importance, since it leads us to a knowledge of the distance of the earth from the sun, and, consequently, by the application of Kepler's law, (Art. 130,) of the distances of all the other planets. Hence, in 1769, great efforts were made throughout the civilized world, under the patronage of different govern-

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230. Why is so much interest attached to the transits of Venus? What efforts were made to observe it in 1769? Why cannot we ascertain the horizontal parallax of the sun in the same way as we do that of the moon?

ments, to observe this phenomenon under circumstances the most favorable for determining the parallax of the sun.

The common methods of finding the parallax of a heavenly body cannot be relied on to a greater degree of accuracy than 4″. In the case of the moon, whose greatest parallax amounts to about 1°, this deviation from absolute accuracy is not material; but it amounts to nearly half the entire parallax of the sun.

231. If the sun and Venus were equally distant from us, they would be equally affected by parallax as viewed by spectators in different parts of the earth, and hence their *relative* situation would not be altered by it; but since Venus, at the inferior conjunction, is only about one third as far off as the sun, her parallax is proportionally greater, and therefore spectators at distant points will see Venus projected on different parts of the solar disk, as the planet traverses the disk. Astronomers avail themselves of this circumstance to ascertain the sun's horizontal parallax. In order to make the difference as large as possible very distant places are selected for observation. Thus in the transit of 1769, among the places selected, two of the most favorable were Wardhuz in Lapland, and Oteheite, one of the South Sea Islands.

The appearance of Venus on the sun's disk, being that of a well defined black spot, and the exactness with which the moment of external or internal contact may be determined, are circumstances favorable to the exactness of the result; and astronomers repose so much confidence in the estimation of the sun's horizontal parallax as derived from the observations on the transit of 1769, that this important element is thought to be ascertained

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231. How is Venus projected on the sun to spectators in different parts of the earth? What places were selected for observing the transit of 1769?

within $\frac{1}{10}$ of a second. The general result of all these observations gives the sun's horizontal parallax 8″.6, or more exactly, 8.″5776.

232. During the transits of Venus over the sun's disk in 1761 and 1769, a sort of penumbral light was observed around the planet by several astronomers, which was thought to indicate an *atmosphere.* This appearance was particularly observable while the planet was coming on and going off the solar disk. The total immersion and emersion were not instantaneous; but as two drops of water when about to separate, form a ligament between them, so there was a dark shade stretched out between Venus and the sun, and when the ligament broke, the planet seemed to have got about an eighth part of her diameter from the limb of the sun. The various accounts of the two transits abound with remarks like these, which indicate the existence of an atmosphere about Venus of nearly the density and extent of the earth's atmosphere. Similar proofs of the existence of an atmosphere around this planet, are derived from appearances of twilight.

The elder astronomers imagined they had discovered a *satellite* accompanying Venus in her transit. If Venus had in reality any satellite, the fact would be obvious at her transits, as the satellite would be projected near the primary on the sun's disk; but later astronomers have searched in vain for any appearances of the kind, and the inference is that former astronomers were deceived by some optical illusion.

Astronomers have detected very high *mountains* on Venus, sometimes reaching to the elevation of 22 miles; and it is remarkable that the highest mountains in Venus, in Mercury, in the moon, and in the earth, are always in the southern hemisphere.

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232. What indications have been observed of an atmosphere about Venus? Has Venus any Satellite? What is said of the mountains of Venus?

CHAPTER VIII.

OF THE SUPERIOR PLANETS—MARS, JUPITER, SATURN, AND URANUS—CERES, PALLAS, JUNO, AND VESTA.

233. THE Superior planets are distinguished from the Inferior, by being seen at all distances from the sun from 0° to 180°. Having their orbits exterior to that of the earth, they of course never come between us and the sun, that is, they never have any inferior conjunction like Mercury and Venus, but they are sometimes seen in superior conjunction, and sometimes in opposition. Nor do they, like the inferior planets, exhibit to the telescope different phases, but, with a single exception, they always present the side that is turned towards the earth fully enlightened. This is owing to their great distance from the earth; for were the spectator to stand upon the sun, he would of course always have the illuminated side of each of the planets turned towards him; but, so distant are all the superior planets except Mars, that they are viewed by us very nearly in the same manner as they would be if we actually stood on the sun.

234. MARS is a small planet, his diameter being only about half of that of the earth, or 4200 miles. He also, at times, comes nearer to the earth than any other planet except Venus. His *mean* distance from the sun is 142,000,000 miles; but his orbit is so eccentric that his distance varies much in different parts of his revolution. Mars is always very near the ecliptic, never varying from

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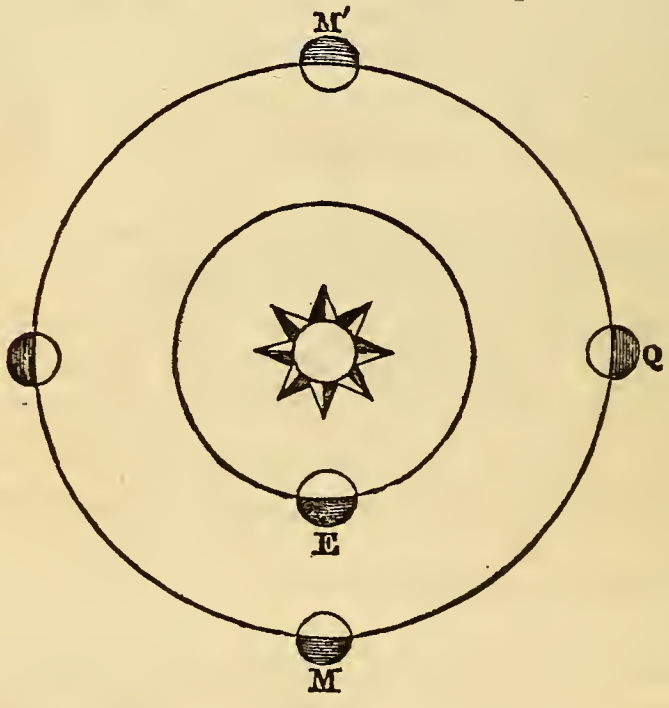
233. Name the Superior Planets. How are they distinguished from the Inferior? Which of them exhibits phases? Why do not the rest?

234. *Mars.*—State his diameter—Mean distance from the sun—inclination of his orbit. How distinguished from the other planets? Why do his brightness and apparent magnitude vary so much? Illustrate by figure 42.

it 2°. He is distinguished from all the planets by his deep red color, and fiery aspect; but his brightness and apparent magnitude vary much at different times, being sometimes nearer to us than at others, by the whole diameter of the earth's orbit, that is, by about 190,000,000 of miles. When Mars is on the same side of the sun with the earth, or at his opposition, he comes within 47,000,000 miles of the earth, and rising about the time the sun sets, surprises us by his magnitude and splendor; but when he passes to the other side of the sun to his superior conjunction, he dwindles to the appearance of a small star, being then 237,000,000 miles from us. Thus, let M (Fig. 42,) represent Mars in opposition, and M′ in the superior conjunction, while E represents the earth. It is obvious that in the former situation, the planet must be nearer to the earth than in the latter by the whole diameter of the earth's orbit.

Fig. 42.



235. Mars is the only one of the superior planets which exhibits phases. When he is towards the quadratures at Q or Q′, it is evident from the figure that only a part of the circle of illumination is turned towards

the earth, such a portion of the remoter part of it being concealed from our view as to render the form more or less gibbous.

236. When viewed with a powerful telescope, the surface of Mars appears diversified with numerous varieties of light and shade. The region around the poles is marked by white spots, which vary their appearance with the changes of seasons in the planets. Hence Dr. Herschel conjectured that they were owing to ice and snow, which alternately accumulates and melts, according to the position of each pole with respect to the sun. It has been common to ascribe the ruddy light of this planet to an extensive and dense atmosphere, which was said to be distinctly indicated, by the gradual diminution of light observed in a star as it approached very near to the planet in undergoing an occultation; but more recent observations afford no such evidence of an atmosphere.

237. By observations on the spots, we learn that Mars revolves on his axis in very nearly the same time with the earth, (24h. 39m. 21s.3); and that the inclination of his axis to that of his orbit is also nearly the same, being 30° 18′ 10″.8.

As the diurnal rotation of Mars is nearly the same as that of the earth, we might expect a similar flattening at the poles, giving to the planet a spheroidal figure. Indeed the compression or ellipticity of Mars greatly exceeds that of the earth, being no less than $\frac{1}{4}$ of the equatorial diameter, while that of the earth is only $\frac{1}{300}$.

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235. Show why Mars should exhibit phases.

236. How is the surface of Mars diversified? What is seen around the poles? What indications are there of ice and snow? To what is the ruddy hue of Mars ascribed?

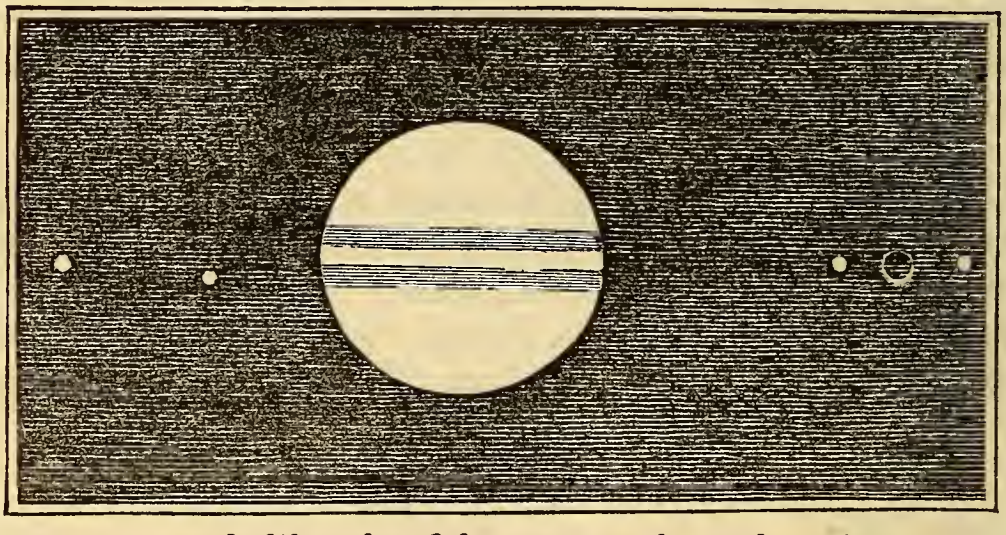
237. How do we learn his revolution on his axis? In what time does it take place? What is the figure of Mars? How does its ellipticity compare with that of the earth?

This remarkable flattening of the poles of Mars has been supposed to arise from a great variation of density in the planet in different parts.

238. JUPITER is distinguished from all the other planets by his vast *magnitude*. His diameter is 89,000 miles, and his volume 1280 times that of the earth. His figure is strikingly spheroidal, the equatorial being larger than the polar diameter in the proportion of 107 to 100. Such a figure might naturally be expected from the rapidity of his diurnal rotation, which is accomplished in about 10 hours. A place on the equator of Jupiter must turn 27 times as fast as on the terrestrial equator. The distance of Jupiter from the sun is nearly 490,000,000 miles, and his revolution around the sun occupies nearly 12 years.

239. The view of Jupiter through a good telescope, (Fig. 43,) is one of the most magnificent and interesting spectacles in astronomy. The disk expands into a large

Fig. 43.



and bright orb like the full moon; the spheroidal figure which theory assigns to revolving spheres, is here pal-

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238. *Jupiter.*—State his diameter, volume, figure, revolution on his axis, velocity of his equator, distance from the sun, periodic time.

pably exhibited to the eye; across the disk, arranged in parallel stripes, are discerned several dusky bands, called *belts;* and four bright satellites, always in attendance, and ever varying their positions, compose a splendid retinue. Indeed, astronomers gaze with peculiar interest on Jupiter and his moons, as affording a miniature representation of the whole solar system, repeating on a smaller scale, the same revolutions, and exemplifying, in a manner more within the compass of our observation, the same laws as regulate the entire assemblage of sun and planets.

240. The *Belts of Jupiter* are variable in their number and dimensions. With the smaller telescopes, only one or two are seen across the equatorial regions; but with more powerful instruments, the number is increased, covering a great part of the whole disk. Different opinions have been entertained by astronomers respecting the cause of the belts; but they have generally been regarded as clouds formed in the atmosphere of the planet, agitated by winds, as is indicated by their frequent changes, and made to assume the form of belts parallel to the equator by currents that circulate around the planet like the trade winds and other currents that circulate around our globe. Sir John Herschel supposes that the belts are not ranges of clouds, but portions of the planet itself brought into view by the removal of clouds and mists, that exist in the atmosphere of the planet through which are openings made by currents circulating around Jupiter.

241. The *Satellites of Jupiter* may be seen with a telescope of very moderate powers. Even a common spy glass will enable us to discern them. Indeed one or two of them have been occasionally seen with the naked eye. In the largest telescopes, they severally appear as

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239. What does the telescopic view of Jupiter exhibit? Why do astronomers regard it with so much interest?

240. Describe Jupiter's Belts—to what are they ascribed?

bright as Sirius. With such an instrument, the view of Jupiter with his moons and belts is truly a magnificent spectacle, a world within itself. As the orbits of the satellites do not deviate far from the plane of the ecliptic, and but little from the equator of the planet, they are usually seen in nearly a straight line with each other extending across the central part of the disk.

242. Jupiter's satellites are distinguished from one another by the denominations of *first*, *second*, *third*, and *fourth*, according to their relative distances from Jupiter, the first being that which is nearest to him. Their apparent motion is oscillatory, like that of a pendulum, going alternately from their greatest elongation on one side to their greatest elongation on the other, sometimes in a straight line, and sometimes in an elliptical curve, according to the different points of view in which we observe them from the earth. They are sometimes stationary; their motion is alternately direct and retrograde; and, in short, they exhibit in miniature all the phenomena of the planetary system. Various particulars of the system are exhibited in the following table. The distances are given in radii of the primary.

Satellite.	Diameter.	Mean Distance.	Sidereal Revolution.
1	2508	6.04853	1d. 18h. 28m.
2	2068	9.62347	3 13 14
3	3377	15.35024	7 3 43
4	2890	26.99835	16 16 32

Hence it appears, first, that Jupiter's satellites are all except the second, somewhat larger than the moon, but that the second satellite is the smallest, and the third the largest of the whole, but the diameter of the latter is only about $\frac{1}{26}$ part of that of the primary; secondly, that the distance of the innermost satellite from the planet

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241. How do the satellites appear to the telescope?

242. Describe the motions of the satellites—magnitudes—distances—periods of revolution.

is three times his diameter, while that of the outermost satellite is nearly fourteen times his diameter; thirdly, that the first satellite completes his revolution around the primary in one day and three fourths, while the fourth satellite requires nearly sixteen and three fourths days.

243. The orbits of the satellites are nearly or quite circular, and deviate but little from the plane of the planet's equator, and of course are but slightly inclined to the plane of its orbit. They are, therefore, in a similar situation with respect to Jupiter as the moon would be with respect to the earth if her orbit nearly coincided with the ecliptic, in which case she would undergo an eclipse at every opposition.

244. The eclipses of Jupiter's satellites, in their general conception, are perfectly analogous to those of the moon, but in their detail they differ in several particulars. Owing to the much greater distance of Jupiter from the sun, and its greater magnitude, the cone of its shadow is much longer and larger than that of the earth. On this account, as well as on account of the little inclination of their orbits to that of their primary, the three inner satellites of Jupiter pass through the shadow, and are totally eclipsed at every revolution. The fourth satellite, owing to the greater inclination of its orbit, sometimes though rarely escapes eclipse, and sometimes merely grazes the limits of the shadow or suffers a partial eclipse. These eclipses, moreover, are not seen, as is the case with those of the moon, from the center of their motion, but from a remote station, and one whose situation with respect to the line of the shadow is variable. This, of course, makes no difference in the *times* of the eclipses, but a very great one in their visibility,

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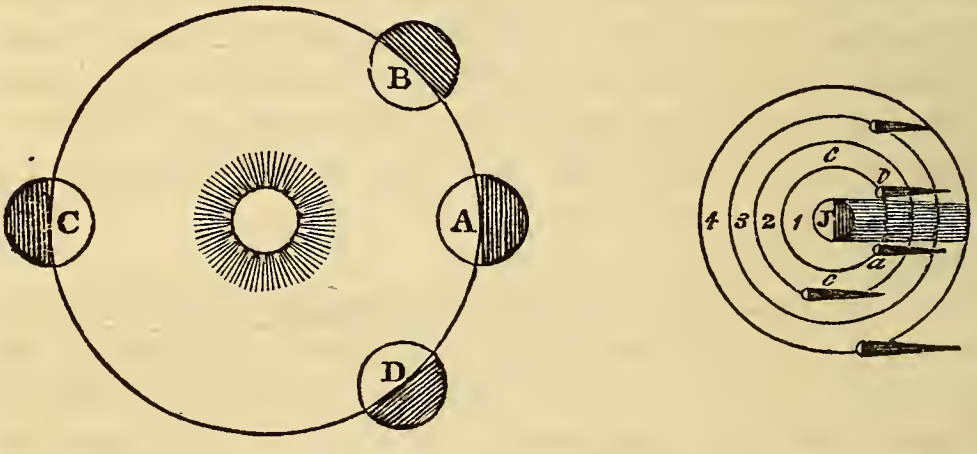
243. What is the shape of their orbits? How situated with regard to the plane of the planet's orbit?

244. Describe the phenomena of their eclipses. Which of them escapes an eclipse? Are these eclipses seen in different parts of the earth at the same moment of absolute time?

and in their apparent situations with respect to the planet at the moment of their entering or quitting the shadow.

245. The eclipses of Jupiter's satellites present some curious phenomena, which will be understood from the following diagrams.

Fig. 44.



Let A, B, C, D, (Fig. 44,) represent the earth in different parts of its orbit; J, Jupiter in his orbit surrounded by his four satellites the orbits of which are marked 1, 2, 3, 4. At *a* the first satellite enters the shadow of the planet, and emerges from it at *b*, and advances to its greatest elongation at *c*. The other satellites traverse the shadow in a similar manner. These appearances will be modified by the place the earth happens to occupy in its orbit, being greatly altered by perspective; but their appearances for any given night as exhibited at Greenwich, are calculated and accurately laid down in the Nautical Almanac.

When one of the satellites is passing between Jupiter and the sun it casts its shadow on the primary as the

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245. Describe the phenomena of the eclipses from figure 44. Will these appearances be affected by the relative position of the earth, with respect to the planet? Does the shadow of a satellite or the satellite itself ever make a transit across the disk of the planet?

moon casts its shadow on the earth in a solar eclipse. We see with the telescope, the shadow traversing the disk. Sometimes the satellite itself is seen projected on the disk; but being illuminated as well as the primary, it is not so easily distinguished as Venus or Mercury, when seen on the sun's disk, since, at the time of their transits, their dark sides are turned towards us. The manner in which these phenomena take place, as seen from the earth in the several positions, A, B, C, D, may be conceived by attentively inspecting the figure. It will be seen, that when the earth is at A or C, the immersions and emersions must take place close to the disk of the planet, but that, in other positions of the earth, as at B or D, the satellite will be seen to enter and leave the shadow at some distance from the primary.

246. The eclipses of Jupiter's satellites have been studied with great attention by astronomers, on account of their affording one of the easiest methods of determining the *longitude*. On this subject Sir J. Herschel remarks: The discovery of Jupiter's satellites by Galileo, which was one of the first fruits of the invention of the telescope, forms one of the most memorable epochs in the history of astronomy. The first astronomical solution of the great problem of "the longitude,"—the most important problem for the interests of mankind that has ever been brought under the dominion of strict scientific principles, dates immediately from their discovery. The final and conclusive establishment of the Copernican system of astronomy, may also be considered as referable to the discovery and study of this exquisite miniature system, in which the laws of the planetary motions, as ascertained by Kepler, and especially that which connects their periods and distances, were speedily traced, and found to be satisfactorily maintained.

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246. Why have the eclipses of Jupiter's satellites been studied with so much attention? Who first discovered these eclipses? What bearing has the system of Jupiter and his satellites upon the Copernican system of astronomy?

247. The entrance of one of Jupiter's satellites into the shadow of the primary being seen like the entrance of the moon into the earth's shadow, at the same moment of absolute time, at all places where the planet is visible, and being wholly independent of parallax; being, moreover, predicted beforehand with great accuracy for the instant of its occurrence at Greenwich, and given in the Nautical Almanac; this would seem to be one of those events (Art. 188,) which are peculiarly adapted for finding the longitude. It must be remarked, however, that the extinction of light in the satellite at its immersion, and the recovery of its light at its emersion, are not instantaneous but gradual; for the satellite, like the moon, occupies some time in entering into the shadow or in emerging from it, which occasions a progressive dimunition or increase of light. The better the light afforded by the telescope with which the observation is made, the later the satellite will be seen at its immersion, and the sooner at its emersion.* In noting the eclipses even of the first satellite, the time must be considered as uncertain to the amount of 20 or 30 seconds; and those of the other satellites involve still greater uncertainty. Two observers, in the same room, observing with different telescopes the same eclipse, will frequently disagree in noting its time to the amount of 15 or 20 seconds; and the difference will be always the same way.

Better methods, therefore, of finding the longitude are now employed, although the facility with which the necessary observations can be made, and the little calculation required, still render this method eligible in many

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247. Explain how these eclipses are used in finding the longitude. What imperfections attend this method? Is this method much employed at present? Why can it not be used at sea?

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* This is the reason why observers are directed in the Nautical Almanac to use telescopes of a *certain power*.

cases where extreme accuracy is not important. As a telescope is essential for observing an eclipse of one of the satellites, it is obvious that this method cannot be practiced at sea.

248. The grand discovery of the *progressive motion of light*, was first made by observations on the eclipses of Jupiter's satellites. In the year 1675, it was remarked by Roemer, a Danish astronomer, on comparing together observations of these eclipses during many successive years, that they take place sooner by about sixteen minutes, (16m.26s.6) when the earth is on the same side of the sun with the planet, than when she is on the opposite side. This difference he ascribed to the progressive motion of light, which takes that time to pass through the diameter of the earth's orbit, making the velocity of light about 192,000 miles per second. So great a velocity startled astronomers at first, and produced some degree of distrust of this explanation of the phenomenon; but the subsequent discovery of what is called the aberration of light, led to an independent estimation of the velocity of light with almost precisely the same result.

249. SATURN comes next in the series as we recede from the sun, and has, like Jupiter, a system within itself, on a scale of great magnificence. In size it is, next to Jupiter, the largest of the planets, being 79,000 miles in diameter, or about 1,000 times as large as the earth. It has likewise belts on its surface and is attended by seven satellites. But a still more wonderfnl appendage is its *Ring*, a broad wheel encompassing the planet at a great distance from it. We have already intimated that Saturn's system is on a grand scale. As, however, Sat-

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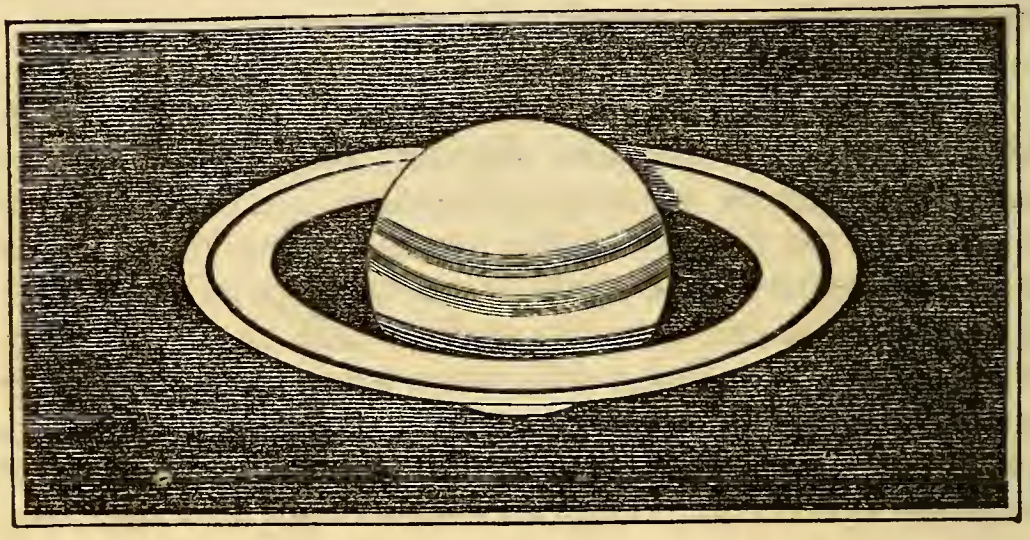
248. How was the progressive motion of light first discovered? Explain the manner of the discovery. How long is light in traversing the diameter of the earth's orbit? What is its velocity per second? How does this agree with that derived from the aberration of light?

urn is distant from us nearly 900,000,000 miles, we are unable to obtain the same clear and striking views of his phenomena as we do of the phenomena of Jupiter, although they really present a more wonderful mechanism.

250. Saturn's ring, when viewed with telescopes of a high power, is found to consist of two concentric rings, separated from each other by a dark space. Although this division of the rings appears to us, on account of our immense distance, as only a fine line, yet it is in reality an interval of not less than about 1800 miles. The dimensions of the whole system are in round numbers as follows:

	Miles.
Diameter of the planet, ...	79,000
From the surface of the planet to the inner ring,	20,000
Breadth of the inner ring, ...	17,000
Interval between the rings, ...	1,800
Breadth of the outer ring, ...	10,500
Extreme dimensions from outside to outside,	176,000

Fig. 45.



The figure represents Saturn as it appears to a powerful telescope, surrounded by its rings, and having its body striped with dark belts, somewhat similar but broader

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249. *Saturn.*—State his diameter and volume. number of satellites, ring, distance from the sun.

and less strongly marked than those of Jupiter, and owing doubtless to a similar cause. That the ring is a solid opake substance, is shown by its throwing its shadow on the body of the planet on the side nearest the sun and on the other side receiving that of the body. From the parallelism of the belts with the plane of the ring, it may be conjectured that the axis of rotation of the planet is perpendicular to that plane; and this conjecture is confirmed by the occasional appearance of extensive dusky spots on its surface, which when watched indicate a rotation parallel to the ring in 10h. 29m. 17s. This motion, it will be remarked, is nearly the same with the diurnal motion of Jupiter, subjecting places on the equator of the planet to a very swift revolution, and occasioning a high degree of compression at the poles, the equatorial being to the polar diameter in the high ratio of 11 to 10. It requires a telescope of high magnifying powers and a strong light, to give a full and striking view of Saturn with his rings and belts and sattellites; for we must bear in mind, that in the distance of Saturn one second of angular measurement corresponds to 4,000 miles, a space equal to the semi-diameter of our globe. But with a telescope of moderate powers, the leading phenomena of the ring itself may be observed.

251. *Saturn's ring, in its revolution around the sun, always remains parallel to itself.*

If we hold opposite to the eye a circular ring or disk like a piece of coin, it will appear as a complete circle when it is at right angles to the axis of vision, but when oblique to that axis it will be projected into an ellipse

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250. How is the ring divided by large telescopes? State the several dimensions of Saturn and his rings. Describe the figure. How is the ring inferred to be a solid opake substance? In what time does Saturn revolve on his axis? What figure does this give to the planet? What kind of telescope is required to see the phenomena of Saturn to advantage?

more and more flattened as its obliquity is increased, until, when its plane coincides with the axis of vision, it is projected into a straight line. Let us place on the table a lamp to represent the sun, and holding the ring at a certain distance inclined a little towards the lamp, let us carry it round the lamp always keeping it parallel to itself. During its revolution it will twice present its edge to the lamp at opposite points, and twice at places 90° distant from those points, it will present its broadest face towards the lamp. At intermediate points, it will exhibit an ellipse more or less open, according as it is nearer one or the other of the preceding positions. It will be seen also that in one half of the revolution the lamp shines on one side of the ring, and in the other half of the revolution on the other side. Such would be the successive appearances of Saturn's ring to a spectator on the sun; and since the earth is, in respect to so distant a body as Saturn, very near the sun, these appearances are presented to us in nearly the same manner as though we viewed them from the sun. Accord dingly, we sometimes see Saturn's ring under the form of a broad ellipse, which grows continually more and more acute until it passes into a line, and we either lose sight of it altogether, or by the aid of the most powerful telescopes, we see it as a fine thread of light drawn across the disk and projecting out from it on each side. As the whole revolution occupies 30 years, and the edge is presented to the sun twice in the revolution, this last phenomenon, namely, the disappearance of the ring, takes place every 15 years.

252. The learner may perhaps gain a clearer idea of the foregoing appearances from the following diagram:

Let A, B, C, &c. represent successive positions of Saturn and his ring in different parts of his orbit, while

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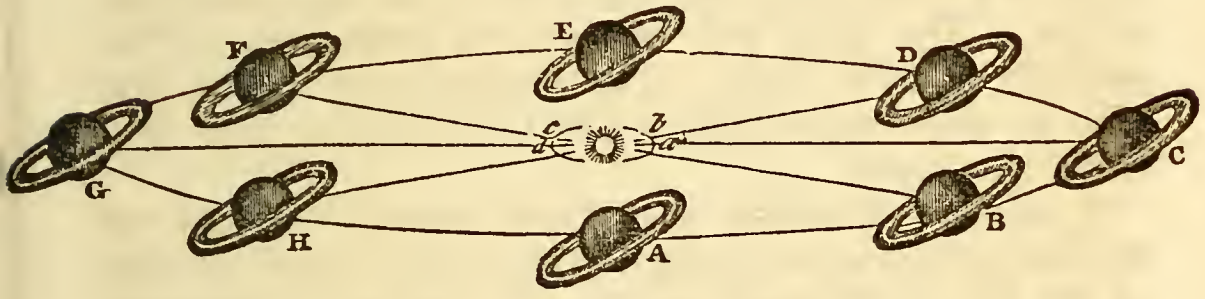
251. How is the position of the ring with respect to itself in all parts of its revolution? How may the various appearances of the ring be represented?

abc represents the orbit of the earth.* Were the ring when at C and G perpendicular to the CG, it would be seen by a spectator situated at *a* or *d* a perfect circle, but being inclined to the line of vision 28° 4′, it is projected into an ellipse. This ellipse contracts in breadth

46.



as the ring passes towards its nodes at A and E, where it dwindles into a straight line. From E to G the ring opens again, becomes broadest at G, and again contracts till it becomes a straight line at A, and from this point expands till it recovers its original breadth at C. These successive appearances are all exhibited to a telescope of moderate powers. The ring is extremely *thin*, since the smallest satellite, when projected on it, more than covers it. The thickness is estimated at 100 miles.

253. *Saturn's ring shines wholly by reflected light derived from the sun.* This is evident from the fact, that that side only which is turned towards the sun is enlightened; and it is remarkable, that the illumination of the ring is greater than that of the planet itself, but

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252. Explain the revolution of the ring by figure 46.

253. Whence does the ring derive its light? What causes occasion the disappearance of the ring? At what intervals do these disappearances occur?

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* It may be remarked by the learner, that these orbits are made so elliptical, not to represent the eccentricity of either the earth's or Saturn's orbit, but merely as the projection of circles seen very obliquely.

the outer ring is less bright than the inner. Although, as we have already remarked, we view Saturn's ring nearly as though we saw it from the sun, yet the plane of the ring produced may pass between the earth and the sun, in which case also the ring becomes invisible, the illuminated side being wholly turned from us. Thus when the ring is approaching its node at E, a spectator at *a* would have the dark side of the ring presented to him. The ring was invisible in 1833, and will be invisible again in 1847. The northern side of the ring will be seen until 1845, when the southern side will come into view.

It appears, therefore, that there are three causes for the disappearance of Saturn's ring; first, when the edge of the ring is presented to the sun; secondly, when the edge is presented to the earth; and thirdly, when the unilluminated side is towards the earth.

254. *Saturn's ring revolves in its own plane in about* $10\frac{1}{2}$ *hours*, (10h. 32m. 15s.4). La Place inferred this from the doctrine of universal gravitation. He proved that such a rotation was necessary, otherwise the matter of which the ring is composed would be precipitated upon its primary. He showed that in order to sustain itself, its period of rotation must be equal to the time of revolution of a satellite, circulating around Saturn at a distance from it equal to that of the middle of the ring, which period would be about $10\frac{1}{2}$ hours. By means of spots in the ring, Dr. Herschel followed the ring in its rotation, and actually found its period to be the same as assigned by La Place,—a coincidence which beautifully exemplifies the harmony of truth.

255. Although the rings are very nearly *concentric* with the planet, yet recent measurements of extreme delicacy

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254. In what time does the ring revolve in its own plane? How was this revolution inferred to exist before it was actually observed?

have demonstrated, that the coincidence is not mathematically exact, but that the center of gravity of the rings describes around that of the body a very minute orbit. This fact, unimportant as it may seem, is of the utmost consequence to the stability of the system of rings. Supposing them mathematically perfect in their circular form, and exactly concentric with the planet, it is demonstrable that they would form (in spite of their centrifugal force) a system in a state of *unstable equilibrium*, which the slightest external power would subvert—not by causing a rupture in the substance of the rings—but by precipitating them *unbroken* on the surface of the planet. The ring may be supposed of an unequal breadth in its different parts, and as consisting of irregular solids, whose common center of gravity does not coincide with the center of the figure. Were it not for this distribution of matter, its equilibrium would be destroyed by the slightest force, such as the attraction of a satellite, and the ring would finally precipitate itself upon the planet.

As the smallest difference of velocity between the planet and its rings must infallibly precipitate the rings upon the planet, never more to separate, it follows either that their motions in their common orbit round the sun, must have been adjusted to each other by an external power, with the minutest precision, or that the rings must have been formed about the planet while subject to their common orbitual motion, and under the full and free influence of all the acting forces.

The rings of Saturn must present a magnificent spectacle from those regions of the planet which lie on their enlightened sides, appearing as vast arches spanning the sky from horizon to horizon, and holding an invariable situation among the stars. On the other hand, in the region beneath the dark side, a solar eclipse of 15 years

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255. Are the rings concentric with the planet? What advantage results from this arrangement? How must the rings appear when seen from the planets?

in duration, under their shadow, must afford (to our ideas) an inhospitable abode to animated beings, but ill compensated by the full light of its satellites. But we shall do wrong to judge of the fitness or unfitness of their condition from what we see around us, when, perhaps, the very combinations which convey to our minds only images of horror may be in reality theatres of the most striking and glorious displays of beneficent contrivance. (Sir J. Herschel.)

256. Saturn is attended by *seven satellites.* Although bodies of considerable size, their great distance prevents their being visible to any telescopes but such as afford a strong light and high magnifying powers. The outermost satellite is distant from the planet more than 30 times the planet's diameter, and is by far the largest of the whole. It is the only one of the series whose theory has been investigated further than suffices to verify Kepler's law of the periodic times, which is found to hold good here as well as in the system of Jupiter. It exhibits, like the satellites of Jupiter, periodic variations of light, which prove its revolution on its axis in the time of a sidereal revolution about Saturn. The next satellite in order, proceeding inwards, is tolerably conspicuous; the three next are very minute, and require pretty powerful telescopes to see them; while the two interior satellites, which just skirt the edge of the ring, and move exactly in its plane, have never been discovered but with the most powerful telescopes which human art has yet constructed, and then only under peculiar circumstances. At the time of the disappearance of the rings (to ordinary telescopes) they were seen by Sir William Herschel with his great telescope, projected along the edge of the ring, and threading like beads the thin fibre of light to

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256. What is the number of Saturn's satellites? How far distant from the planet is the outermost satellite? Do the satellites follow Kepler's third law? Which of the satellites are easily seen? Do they undergo eclipses?

which the ring is then reduced. Owing to the obliquity of the ring, and of the orbits of the satellites to that of their primary, there are no eclipses of the satellites, the two interior ones excepted, until near the time when the ring is seen edgewise.

257. URANUS is the remotest planet belonging to our system, and is rarely visible except to the telescope. Although his diameter is more than four times that of the earth, (35,112 miles,) yet his distance from the sun is likewise nineteen times as great as the earth's distance, or about 1,800,000,000 miles. His revolution around the sun occupies nearly 84 years, so that his position in the heavens for several years in succession is nearly stationary. His path lies very nearly in the ecliptic, being inclined to it less than one degree, (46′ 28″.44.)

The sun himself when seen from Uranus dwindles almost to a star, subtending as it does an angle of only 1′ 40″; so that the surface of the sun would appear there 400 times less than it does to us.

This planet was discovered by Sir William Herschel on the 13th of March 1781. His attention was attracted to it by the largeness of its disk in the telescope; and finding that it shifted its place among the stars, he at first took it for a comet, but soon perceived that its orbit was not eccentric like the orbits of comets, but nearly circular like those of the planets. It was then recognized as a new member of the planetary system, a conclusion which has been justified by all succeeding observations.

258. Uranus is attended by *six satellites.* So minute objects are they, that they can be seen only by powerful telescopes. Indeed, the existence of more than two is still considered as somewhat doubtful. These two,

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257. *Uranus.*—State his diameter—distance from the sun—periodic time—inclination of his orbit. How would the sun appear from Uranus? State the history of his discovery

however, offer remarkable, and indeed quite unexpected and unexampled peculiarities. Contrary to the unbroken analogy of the whole planetary system, *the planes of their orbits are nearly perpendicular to the ecliptic*, being inclined no less than 78° 58′ to that plane, and in these orbits *their motions are retrograde ;* that is, instead of advancing from west to east around their primary, as is the case with all the other planets and satellites, they move in the opposite direction. With this exception, all the motions of the planets, whether around their own axes, or around the sun, are from west to east. The sun, himself, turns on his axis from west to east; all the primary planets revolve around the sun from west to east, their revolutions on their own axes are also in the same direction; all the secondaries, with the single exception above mentioned, move about their primaries from west to east; and, finally, such of the secondaries as have been discovered to have a diurnal revolution, follow the same course. Such uniformity among so many motions, could have resulted only from forces impressed upon them by the same omnipotent hand; and few things in the creation more distinctly proclaim that God made the world.

THE NEW PLANETS, CERES, PALLAS, JUNO, AND VESTA.

259. The commencement of the present century was rendered memorable in the annals of astronomy, by the discovery of four new planets between Mars and Jupiter. Kepler, from some analogy which he found to subsist among the distances of the planets from the sun, had long before suspected the existence of one at this distance; and his conjecture was rendered more probable by the discovery of Uranus, which follows the analogy

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258. By how many satellites is Uranus attended? What is said of their minuteness? What remarkable peculiarities have they? In what direction are the motions of all the bodies in the solar system? What does this fact indicate with respect to their origin?

of the other planets. So strongly, indeed, were astronomers impressed with the idea that a planet would be found between Mars and Jupiter, that, in the hope of discovering it, an association was formed on the continent of Europe of twenty-four observers, who divided the sky into as many zones, one of which was allotted to each member of the association. The discovery of the first of these bodies was however made accidentally by Piazzi, an astronomer of Palermo, on the first of January, 1801. It was shortly afterwards lost sight of on account of its proximity to the sun, and was not seen again until the close of the year, when it was re-discovered in Germany. Piazzi called it *Ceres*, in honor of the tutelary goddess of Sicily; and her emblem, the sickle ⚳, has been adopted as its appropriate symbol.

The difficulty of finding Ceres induced Dr. Olbers, of Bremen, to examine with particular care all the small stars that lie near her path, as seen from the earth; and while prosecuting these observations, in March, 1802, he discovered another similar body, very nearly at the same distance from the sun, and resembling the former in many other particulars. The discoverer gave to this second planet the name of *Pallas*, choosing for its symbol the lance ⚴, the characteristic of Minerva.

260. The most surprising circumstance connected with the discovery of Pallas, was the existence of two planets at nearly the same distance from the sun, and apparently having a common node. On account of this singularity, Dr. Olbers was led to conjecture that Ceres and Pallas are only fragments of a larger planet, which had formerly circulated at the same distance, and been shattered by some internal convulsion. The hypothesis suggested the probability that there might be other frag-

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259. Name the New Planets. When were they discovered? What had been conjectured previous to their discovery? Who discovered the first? What is its name? How was Pallas discovered?

ments, whose orbits, however they might differ in eccentricity and inclination, might be expected to cross the ecliptic at a common point, or to have the same node. Dr. Olbers, therefore, proposed to examine carefully every month, the two opposite parts of the heavens in which the orbits of Ceres and Pallas intersect one another, with a view to the discovery of other planets, which might be sought for in those parts with greater chance of success than in a wider zone, embracing the entire limits of these orbits. Accordingly, in 1804, near one of the nodes of Ceres and Pallas, a third planet was discovered. This was called *Juno*, and the character ⚵ was adopted for its symbol, representing the starry sceptre of the queen of Olympus. Pursuing the same researches, in 1807, a fourth planet was discovered, to which was given the name of *Vesta*, and for its symbol the character ⚶ was chosen—an altar surmounted with a censer holding the sacred fire.

After this historical sketch, it will be sufficient to classify under a few heads the most interesting particulars relating to the New Planets.

261. The *average distance* of these bodies from the sun is 261,000,000 miles; and it is remarkable that their orbits are very near together. Taking the distance of the earth from the sun for unity, their respective distances are 2.77, 2.77, 2.67, 2.37.

As they are found to be governed, like the other members of the solar system, by Kepler's law, that regulates the distances and times of revolution, their *periodical times* are of course pretty nearly equal, averaging about $4\frac{1}{2}$ years.

In respect to the *inclination of their orbits*, there is considerable diversity. The orbit of Vesta is inclined

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260. How do Ceres and Pallas compare in distance from the sun and the place of their nodes? What hypothesis did Olbers adopt? State the circumstances connected with the discovery of Juno and Vesta.

to the ecliptic only about 7°, while that of Pallas is more than 34°. They all therefore have a higher inclination than the orbits of the old planets, and of course make excursions from the ecliptic beyond the limits of the Zodiac.

The *eccentricity of their orbits* is also, in general, greater than that of the old planets; and the eccentricities of the orbits of Pallas and Juno exceed that of the orbit of Mercury.

Their *small size* constitutes one of their most remarkable peculiarities. The difficulty of estimating the apparent diameters of bodies at once so very small and so far off, would lead us to expect different results in the actual estimates. Accordingly, while Dr. Herschel estimates the diameter of Pallas at only 80 miles, Schroeter places it as high as 2,000 miles, or about the size of the moon. The volume of Vesta is estimated at only one fifteen thousandth part of the earth's, and her surface is only about equal to that of the kingdom of Spain. These little bodies are surrounded by *atmospheres* of great extent, some of which are uncommonly luminous, and others appear to consist of nebulous or vapory matter. These planets in general shine with a more vivid light than might be expected from their great distance and diminutive size.

CHAPTER IX.

MOTIONS OF THE PLANETARY SYSTEM—QUANTITY OF MATTER IN THE SUN AND PLANETS—STABILITY OF THE SOLAR SYSTEM.

262. We have waited until the learner may be supposed to be familiar with the contemplation of the heav-

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261. What is the average distance of the New Planets from the sun? How do these orbits lie with respect to each other? Are they subject to Kepler's third law? What is their average periodical time? What is said of the inclination of their orbits? Also, of the eccentricity? What is their size?

enly bodies, individually, before inviting his attention to a systematic view of the planets, and of their motions around the sun. The time has now arrived for entering more advantageously upon this subject, than could have been done at an earlier period.

There are two methods of arriving at a knowledge of the motions of the heavenly bodies. One is to begin with the *apparent*, and from these to deduce the *real* motions; the other is, to begin with considering things as they really are in nature, and then to inquire why they appear as they do. The latter of these methods is by far the more eligible; it is much easier than the other, and proceeding from the less difficult to that which is more difficult, from motions that are very simple to such as are complicated, it finally puts the learner in possession of the whole machinery of the heavens. We shall, in the first place, therefore, endeavor to introduce the learner to an acquaintance with the simplest motions of the planetary system, and afterwards to conduct him gradually through such as are more complicated and difficult.

263. Let us first of all endeavor to acquire an adequate idea of *absolute space*, such as existed before the creation of the world. We shall find it no easy matter to form a correct notion of infinite space; but let us fix our attention, for some time, upon extension alone, devoid of every thing material, without light or life, and without bounds. Of such a space we could not predicate the ideas of up or down, east, west, north, or south, but all reference to our own horizon (which habit is the most difficult of all to eradicate from the mind) must be completely set aside. Into such a void we would introduce the Sun. We would contemplate this body alone, in the midst of boundless space, and continue to fix the at-

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262. What are the two methods of studying the motions of the heavenly bodies? Which method is best? What motions will be first considered?

tention upon this object, until we had fully settled its relations to the surrounding void. The ideas of up and down would now present themselves, but as yet there would be nothing to suggest any notion of the cardinal points. We suppose ourselves next to be placed on the surface of the sun, and the firmament of stars to be lighted up. The slow revolution of the sun on his axis, would be indicated by a corresponding movement of the stars in the opposite direction; and in a period equal to more than 25 of our days, the spectator would see the heavens perform a complete revolution around the sun, as he now sees them revolve around the earth once in 24 hours. The point of the firmament where no motion appeared, would indicate the position of one of the poles, which being called North, the other cardinal points would be immediately suggested.

Thus prepared, we may now enter upon the consideration of the *planetary motions.*

264. Standing on the sun, we see all the planets moving slowly around the celestial sphere, nearly in the same great highway, and in the same direction from west to east. They move, however, with very unequal velocities. Mercury makes very perceptible progress from night to night, like the moon revolving about the earth, his daily progress eastward being one third as great as that of the moon, since he completes his entire revolution in about three months. If we watch the course of this planet from night to night, we observe it in its revolution, to cross the ecliptic in two opposite points of the heavens, and wander about 7° from that plane at its greatest distance from it. Knowing the position of the orbit of Mercury with respect to the ecliptic, we may now, in imagination, represent that orbit by a

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263. How can we form a correct idea of absolute space? What can we predicate of such a space? If the sun were placed in such a void, what new ideas would present themselves? How should we get a knowledge of the cardinal points?

great circle passing through the center of the planet and the center of the sun, and cutting the plane of the ecliptic in two opposite points at an angle of 7°. We may imagine the intersection of these two great circles with the celestial vault to be marked out in plain and palpable lines on the face of the sky; but we must bear in mind that these orbits are mere *mathematical planes*, having no permanent existence in nature, any more than the path of an eagle flying through the sky; and if we conceive of their orbits marked on the celestial vault, we must be careful to attach to the representation the same notion as to a thread or wire, carried round to trace out the course pursued by a horse in a race-ground.*

The *planes* of both the ecliptic and the orbit of Mercury, may be conceived of as indefinitely extended to a great distance until they meet the sphere of the stars; but the *lines* which the earth and Mercury describe in those planes, that is, their orbits may be conceived of as comparatively *near to the sun.* Could we now for a moment be permitted to imagine that the planes of the ecliptic, and of the orbit of Mercury, were made of thin plates of glass, and that the paths of the respective planets were marked out on their planes in distinct lines, we should perceive the orbit of the earth to be almost a perfect circle, while that of Mercury would appear distinctly elliptical. But having once made use of a palpable sur-

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264. Where must the spectator be placed in order to see the real motions of the planets? How would the motions of the several planets appear from this station? State the particular movements of Mercury. How may we imagine the ecliptic and the orbit of Mercury to be represented on the sky? How shall we conceive of the *planes* of these orbits as distinguished from the orbit itself?

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* It would seem superfluous to caution the reader on so plain a point, did not the experience of the instructor constantly show that young learners, from the habit of seeing the celestial motions represented in orreries and diagrams, almost always fall into the absurd notion of considering the orbits of the planets as having a distinct and independent existence.

face and visible lines to aid us in giving position and figure to the planetary orbits, let us now throw aside these devices, and hereafter conceive of these planes and orbits as they are in nature, and learn to refer a body to a mere *mathematical* plane, and to trace its path in that plane through absolute space.

265. A clear understanding of the motions of Mercury and of the relation of its orbit to the plane of the ecliptic, will render it easy to understand the same particulars in regard to each of the other planets. Standing on the sun we should see each of the planets pursuing a similar course to that of Mercury, all moving from west to east, with motions differing from each other chiefly in two respects, namely, in their velocities, and in the distances to which they ever recede from the ecliptic.

The earth revolves about the sun very much like Venus, and to a spectator on the sun, the motions of these two planets would exhibit much the same appearances. We have supposed the observer to select the plane of the earth's orbit as his standard of reference, and to see how each of the other orbits is related to it; but such a selection of the ecliptic is entirely arbitrary; the spectator on the sun, who views the motions of the planets as they actually exist in nature, would make no such distinction between the different orbits, but merely inquire how they were mutually related to each other. Taking, however, the ecliptic as the plane to which all the others are referred, we do not, as in the case of the other planets, inquire how its plane is *inclined*, nor what are its *nodes*, since it has neither inclination nor node.

266. The attempt to exhibit the motions of the solar system, and the positions of the planetary orbits by

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265. If we stood on the sun, how should we see each of the planets revolve? Why is the earth's orbit selected as the standard of reference? Would the spectator on the sun make any such distinction?

means of diagrams, or even orreries, is usually a failure The student who relies exclusively on such aids as these, will acquire ideas on this subject that are both inadequate and erroneous. They may aid reflection, but can never supply its place. The impossibility of representing things in their just proportions will be evident when we reflect, that to do this, if, in an orrery, we make Mercury as large as a cherry, we should require to represent the sun by a globe six feet in diameter. If we preserve the same proportions in regard to distance, we must place Mercury 250 feet, and Uranus 12,500 feet, or more than two miles from the sun. The mind of the student of astronomy must, therefore, raise itself from such imperfect representations of celestial phenomena as are afforded by artificial mechanism, and, transferring his contemplations to the celestial regions themselves, he must conceive of the sun and planets as bodies that bear an insignificant ratio to the immense spaces in which they circulate, resembling more a few little birds flying in the open sky, than they do the crowded machinery of an orrery.

267. Having acquired as correct an idea as we are able of the planetary system, and of the positions of the orbits with respect to the ecliptic, let us next inquire into the nature and causes of the *apparent motions.*

The apparent motions of the planets are exceedingly unlike the real motions, a fact which is owing to two causes; first, *we view them out of the center of their orbits;* secondly, *we are ourselves in motion.* From the first cause, the apparent places of the planets are greatly changed by perspective; and from the second cause,

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266. What is said of the attempt to represent the positions and motions of the solar system by diagrams and orreries? Give examples.

267. Are the apparent motions of the planets like the real motions? What makes them different? How does each cause operate? What is the heliocentric place, and what the geocentric place of a planet?

we attribute to the planets changes of place which arise from our own motions of which we are unconscious.

The situation of a heavenly body as seen from the center of the sun is called its *heliocentric* place; as seen from the center of the earth, its *geocentric* place. The geocentric motions of the planets must, according to what has just been said, be far more irregular and complicated than the heliocentric.

268. The apparent motions of the Inferior Planets as seen from the earth, have been already explained in articles 216 and 217; from which it appeared, that Mercury and Venus move backwards and forwards across the sun, the former never being seen farther than 29° and the latter never more than 47° from that luminary. It was also shown that while passing from the greatest elongation on one side to the greatest elongation on the other side, through the superior conjunction, the apparent motions of these planets are accelerated by the motion of the earth; but that while moving through the inferior conjunction, at which time their motions are retrograde, they are apparently retarded by the earth's motion. Let us now see what are the geocentric motions of the Superior Planets.

269. Let A, B, C, (Fig. 47,) represent the earth in different positions in its orbit, and M a superior planet as Mars, and NR an arc of the concave sphere of the heavens. First, suppose the planet to remain at rest in M, and let us see what apparent motions it will receive from the real motions of the earth. When the earth is at B, it will see the planet in the heavens at N; and as the earth moves successively through, C, D, E, F, the planet will appear to move through O, P, Q, R. B and F are the two points of greatest elongation of the earth from the sun as seen from the planet; hence between

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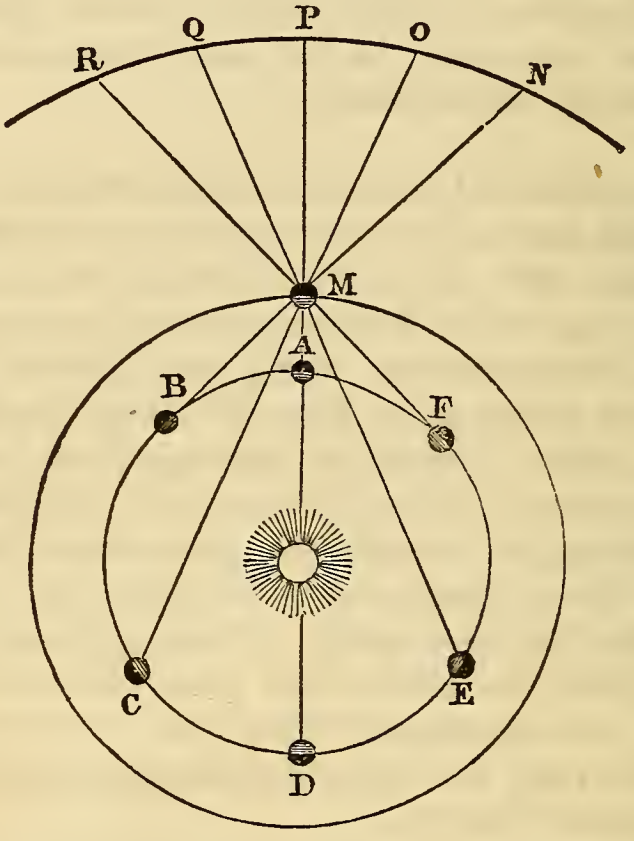
268. Describe the apparent motions of Mercury and Venus from figure 40.

these two points, while passing through the part of her orbit most remote from the planet, (when the planet is seen in superior conjunction,) the earth by her own mo-

Fig. 47.



tion gives an apparent motion to the planet in the order of the signs—that is, the apparent motion given by the earth is *direct.* But in passing from F to B through A, when the planet is seen in opposition, the apparent motion given to the planet by the earth's motion is from R to N, and is therefore *retrograde.* As the arc described by the earth, when the motion is direct, is much greater than when the motion is retrograde, while the apparent arc of the heavens described by the planet from N to R in the one case, and from R to N in the other, is the

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269. Describe the motions of the Superior Planets from figure 47. The planet remaining *at rest*, what apparent motions will the motion of the earth impart to it, when in opposition? What when in superior conjunction?

same in both cases, the retrograde motion is much swifter than the direct, being performed in much less time.

270. But the superior planet is not in fact at rest, as we have supposed, but is all the while moving eastward, though with a slower motion than the earth. Indeed, with respect to the remotest planets as Saturn and Uranus, the forward motion is so exceedingly slow that the above representation is nearly true for a single year. Still, the effect of the real motions of all the superior planets eastward, is to increase the direct apparent motion communicated by the earth and to diminish the retrograde motion.

If Mars stood still while the earth went round the sun, then a second opposition as at A, would occur at the end of one year from the first; but while the earth is performing this circuit, Mars is also moving the same way, more than half as fast, so that when the earth returns to A, the planet has already performed more than half the same circuit, and will have completed its whole revolution before the earth comes up with it. Indeed, Mars, after having been once seen in opposition, does not come into opposition again until after two years and fifty days. And since the planet is then comparatively very near to us, and appears very large and bright, rising unexpectedly about the time the sun sets, he surprises the world as though it were some new celestial body. But on account of the slow progress of Saturn and Uranus, we find after having performed one circuit around the sun, that they are but little advanced beyond where we left them at the last opposition. The time between one opposition of Saturn and another is only a year and thirteen days.

It appears, therefore that the superior planets steadily pursue their course around the sun, but that their appar-

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270. How does the real motion of the planet modify the foregoing results? How in respect to the remotest planets, as Uranus, and how in respect to a nearer planet as Mars? How often is Mars in opposition? What is his appearance then?

ent retrograde motion when in opposition, is occasioned by our passing by them with a swifter motion, like the apparent backward motion of a vessel when we overtake it and pass rapidly by it in a steamboat.

QUANTITY OF MATTER IN THE SUN AND PLANETS.

271. It would seem at first view very improbable that an inhabitant of this earth should be able to weigh the sun and planets, and estimate the exact quantity of matter which they severally contain. But the principles of Universal Gravitation conduct us to this result, by a process remarkable for its simplicity. By comparing the relations of a few elements that are known to us, we ascend to the knowledge of such as appeared to be beyond the pale of human investigation. We learn the quantity of matter in a body from the force of gravity it exerts, and this force is estimated by its effects. Hence worlds are weighed with as much ease as a pebble or an article of merchandise.

272. The sun contains about 355,000 times as much matter as the earth, and 800 times as much matter as all the planets. This however, is owing rather to its great size than to the specific gravity of its materials, for the *density* of the sun is only one fourth as great as that of the earth. The earth is nearly $5\frac{1}{2}$ times as heavy as water, but the sun is only a little heavier than that fluid. The planets near the sun are in general more dense than

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271. What is said of the apparent difficulty of weighing the sun and planets? What great principles lead us to this result? How do we learn the quantity of matter in the bodies of the solar system?

272. How much more matter does the sun contain than the earth? How much more than all the planets? What is the density of the sun compared with that of the earth? How much heavier is the earth than water? How much heavier is the sun than water? Which of the planets have the greatest density? How heavy is Mercury? How heavy is Saturn?

those more remote; Mercury being heavier than lead, while Saturn is as light as a cork. The decrease in density however, is not entirely regular, since Venus is a little lighter than the earth, while Jupiter is heavier than Mars, and Uranus than Saturn.

STABILITY OF THE SOLAR SYSTEM.

273. The *perturbations* occasioned by the motions of the planets by their action on each other are very numerous, since every body in the system exerts an attraction on every other, in conformity with the law of Universal Gravitation. Venus and Mars, approaching as they do at times comparatively near to the earth, sensibly disturb its motions, and the satellites of the remoter planets greatly disturb each other's movements.

274. The derangement which the planets produce in the motion of one of their number will be very small in the course of one revolution; but this gives us no security that the derangement may not become very large in the course of many revolutions. The cause acts perpetually, and it has the whole extent of time to work in. Is it not easily conceivable then, that in the lapse of ages, the derangements of the motions of the planets may accumulate, the orbits may change their form, and their mutual distances may be much increased or diminished? Is it not possible that these changes may go on without

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273. What is said of the perturbations occasioned by the action of the planets on each other? Which planets in particular, disturb the motions of the earth?

274. How is the derangement produced by the planets upon any one of them, in a single revolution? What may be the ultimate effect of these disturbing forces? What would be the consequence of increasing the eccentricity of the earth's orbit—or of bringing the moon nearer the earth—or of altering the positions of the planets with respect to that of the earth? What changes are actually going on in the motions of the heavenly bodies?

limit, and end in the complete subversion and ruin of the system? If, for instance, the result of this mutual gravitation should be to increase considerably the eccentricity of the earth's orbit, or to make the moon approach continually nearer and nearer to the earth at every revolution, it is easy to see that in the one case, our year would change its character, producing a far greater irregularity in the distribution of the solar heat: in the other, our satellite must fall to the earth, occasioning a dreadful catastrophe. If the positions of the planetary orbits with respect to that of the earth, were to change much, the planets might sometimes come very near us, and thus increase the effect of their attraction beyond calculable limits. Under such circumstances we might have years of unequal length, and seasons of capricious temperature; planets and moons of portentous size and aspect glaring and disappearing at uncertain intervals; tides like deluges sweeping over whole continents; and, perhaps, the collision of two of the planets, and the consequent destruction of all organization on both of them. The fact really is, that changes are taking place in the motions of the heavenly bodies, which have gone on progressively from the first dawn of science. The eccentricity of the earth's orbit has been diminishing from the earliest observations to our times. The moon has been moving quicker from the time of the first recorded eclipses, and is now in advance by about four times her own breadth, of what her own place would have been if it had not been affected by this acceleration. The obliquity of the ecliptic also, is in a state of diminution, and is now about two fifths of a degree less than it was in the time of Aristotle. (Whewell, in the Bridgewater Treatises, p. 128.)

275. But amid so many seeming causes of irregularity, and ruin, it is worthy of grateful notice, that effectual provision is made for the *stability of the solar system.* The full confirmation of this fact, is among the grand results of Physical Astronomy. Newton did not undertake to demonstrate either the stability or insta-

bility of the system. The decision of this point required a great number of preparatory steps and simplifications, and such progress in the invention and improvement of mathematical methods, as occupied the best mathematicians of Europe for the greater part of the last century. Towards the end of that time, it was shown by La Grange and La Place, that the arrangements of the solar system are stable; that, in the long run, the orbits and motions remain unchanged; and that the changes in the orbits, which take place in shorter periods, never transgress certain very moderate limits. Each orbit undergoes deviations on this side and on that side of its average state; but these deviations are never very great, and it finally recovers from them, so that the average is preserved. The planets produce perpetual perturbations in each other's motions, but these perturbations are not indefinitely progressive, but periodical, reaching a maximum value and then diminishing. The periods which this restoration requires are for the most part enormous,—not less than thousands, and in some instances millions of years. Indeed some of these apparent derangements, have been going on in the same direction from the creation of the world. But the restoration is in the sequel as complete as the derangement; and in the mean time the disturbance never attains a sufficient amount seriously to affect the stability of the system. (Whewell, in the Bridgewater Treatises, p. 128.) I have succeeded in demonstrating (says La Place) that, whatever be the masses of the planets, in consequence of the fact that they all move in the same direction, in orbits of small eccentricity, and but slightly inclined to each other, their secular irregularities are periodical and included within narrow limits; so that the planetary system will only oscillate about a

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275. Is the system stable? Did Newton prove this? Who fully established this point? Have all the inequalities of the planetary motions a fixed period? How long are some of these periods?

mean state, and will never deviate from it except by a very small quantity. The ellipses of the planets have been and always will be nearly circular. The ecliptic will never coincide with the equator; and the entire extent of the variation in its inclination, cannot exceed three degrees.

276. To these observations of La Place, Professor Whewell adds the following on the importance, to the stability of the solar system, of the fact that those planets which have *great masses* have orbits of *small eccentricity*. The planets Mercury and Mars, which have much the largest eccentricity among the old planets, are those of which the masses are much the smallest. The mass of Jupiter is more than two thousand times that of either of these planets. If the orbit of Jupiter were as eccentric as that of Mercury, all the security for the stability of the system, which analysis has yet pointed out, would disappear. The earth and the smaller planets might, by the near approach of Jupiter at his perihelion, change their nearly circular orbits into very long ellipses, and thus might fall into the sun, or fly off into remote space. It is further remarkable that in the newly discovered planets, of which the orbits are still more eccentric than that of Mercury, the masses are still smaller, so that the same provision is established in this case also.

CHAPTER X.

OF COMETS.

277. A Comet, when perfectly formed, consists of three parts, the Nucleus, the Envelope, and the Tail. The *Nucleus*, or body of the comet, is generally distinguished by its forming a bright point in the center of the head, conveying the idea of a solid, or at least of a

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276. What planets have orbits of small eccentricity? How does this fact contribute to the stability of the system?

very dense portion of matter. Though it is usually exceedingly small when compared with the other parts of the comet, yet it sometimes subtends an angle capable of being measured by the telescope. The *Envelope*, (sometimes called the *coma*) is a dense nebulous covering, which frequently renders the edge of the nucleus so indistinct, that it is extremely difficult to ascertain its diameter with any degree of precision. Many comets have no nucleus, but present only a nebulous mass extremely attenuated on the confines, but gradually increasing in density towards the center. Indeed there is a regular gradation of comets, from such as are composed merely of a gaseous or vapory medium, to those which have a well defined nucleus. In some instances on record, astronomers have detected with their telescopes small stars through the densest part of a comet.

The *Tail* is regarded as an expansion or prolongation of the coma; and, presenting as it sometimes does, a train of appalling magnitude, and of a pale, disastrous light, it confers on this class of bodies, their peculiar celebrity.

Fig 48.

These several parts are exhibited in figure 48, which represents the appearance of the comet of 1680.

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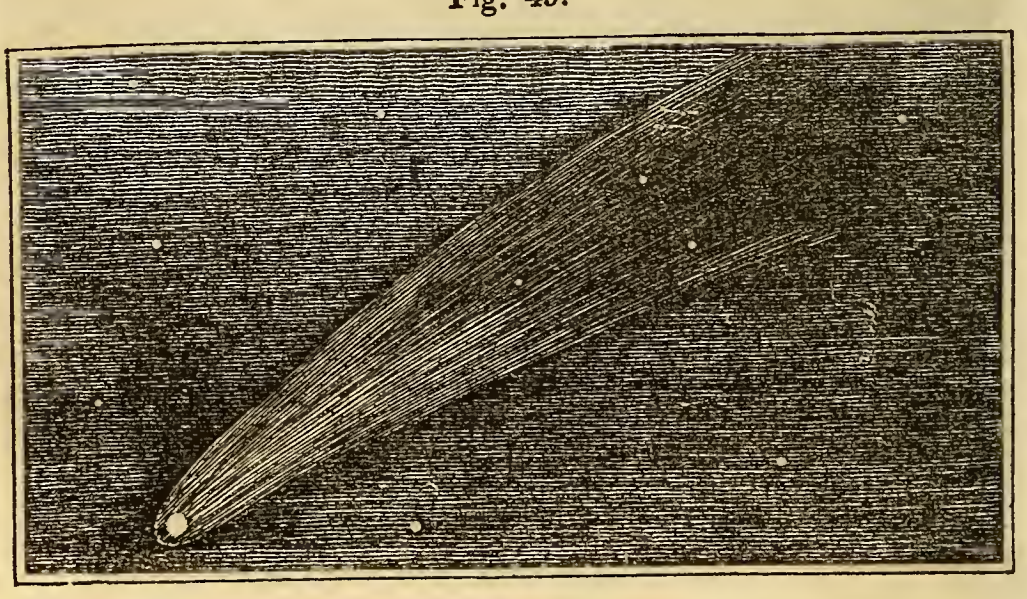
277. Of what three parts does a comet consist? Describe each.

278. The *number* of comets belonging to the solar system, is probably very great. Many, no doubt, escape observation by being above the horizon in the day time. Seneca mentions, that during a total eclipse of the sun, which happened 60 years before the Christian era, a large and splendid comet suddenly made its appearance, being very near the sun. The elements of at least 130 have been computed, and arranged in a table for future comparison. Of these *six* are particularly remarkable, viz. the comets, of 1680, 1770, and 1811; and those which bear the names of Halley, Biela, and Encke. The comet of 1680, was remarkable not only for its astonishing size and splendor, and its near approach to the sun, but is celebrated for having submitted itself to the observations of Sir Isaac Newton, and for having enjoyed the signal honor of being the first comet whose elements were determined on the sure basis of mathematics. The comet of 1770, is memorable for the changes its orbit has undergone by the action of Jupiter, as will be more particularly related in the sequel. The comet of 1811 was the most remarkable in its appearance of all that have been seen in the present century. It had scarcely any perceptible nucleus, but its train

Fig. 49.



was very long and broad, as is represented in figure 49. Halley's comet (the same which re-appeared in 1835) is

distinguished as that whose return was first successfully predicted, and whose orbit is best determined; and Biela's and Encke's comets are well known for their short periods of revolution, which subject them frequently to the view of astronomers.

279. In *magnitude* and *brightness* comets exhibit a great diversity. History informs us of comets so bright as to be distinctly visible in the day time, even at noon and in the brightest sunshine. Such was the comet seen at Rome a little before the assassination of Julius Cæsar. The comet of 1680 covered an arc of the heavens of 97°, and its length was estimated at 123,000,000 miles. That of 1811, had a nucleus of only 428 miles in diameter, but a tail 132,000,000 miles long. Had it been coiled around the earth like a serpent, it would have reached round more than 5,000 times. Other comets are of exceedingly small dimensions, the nucleus being estimated at only 25 miles; and some which are destitute of any perceptible nucleus, appear to the largest telescopes, even when nearest to us, only as a small speck of fog, or as a tuft of down. The majority of comets can be seen only by the aid of the telescope.

The same comet, indeed, has often very different aspects, at its different returns. Halley's comet in 1305 was described by the historians of that age, as the comet of terrific magnitude; (*cometa horrendæ magnitudinis*;) in 1456 its tail reached from the horizon to the zenith, and inspired such terror, that by a decree of the Pope of Rome, public prayers were offered up at noon-day in all the Catholic churches to deprecate the wrath of heaven, while in 1682, its tail was only 30° in length, and in 1759

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278. What is said of the number of comets? How many have been arranged in a table. Specify the six that are most remarkable. State particulars respecting each.

279. What is said of the magnitude and brightness of comets? What was the length of the comet of 1680? Ditto of 1811? Has the same comet different aspects at different returns? Example in Halley's comet.

it was visible only to the telescope, until after it had passed the perihelion. At its recent return in 1835, the greatest length of the tail was about 12°. These changes in the appearances of the same comet, are partly owing to the different positions of the earth with respect to them, being sometimes much nearer to them when they cross its track than at others; also one spectator so situated as to see the coma at a higher angle of elevation or in a purer sky than another, will see the train longer than it appears to another less favorably situated; but the extent of the changes are such as indicate also a real change in magnitude and brightness.

280. The *periods* of comets in their revolutions around the sun, are equally various. Encke's comet, which has the shortest known period, completes its revolution in $3\frac{1}{3}$ years, or more accurately, in 1208 days; while that of 1811 is estimated to have a period of 3383 years.

281. The *distances* to which different comets recede from the sun, are also very various. While Encke's comet performs its entire revolution within the orbit of Jupiter, Halley's comet recedes from the sun to twice the distance of Uranus, or nearly 3600,000,000 miles. Some comets, indeed, are thought to go to a much greater distance from the sun than this, while some even are supposed to pass into parabolic or hyperbolic orbits, and never to return.

282. Comets shine *by reflecting the light of the sun.* In one or two instances they have exhibited distinct *phases*, although the nebulous matter with which the nucleus is surrounded, would commonly prevent such

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280. How are the periods of comets? What is that of Encke's comet, and that of the comet of 1811?

281. How are the distances of comets from the sun? Compare Encke's and Halley's. Do comets always return to the sun?

phases from being distinctly visible, even when they would otherwise be apparant. Moreover, certain qualities of polarized light enable the optician to decide whether the light of a given body is direct or reflected; and M. Arago, of Paris, by experiments of this kind on the light of the comet of 1819, ascertained it to be reflected light.

283. The tail of a comet usually increases very much as it approaches the sun; and it frequently does not reach its maximum until after the perihelion passage. In receding from the sun, the tail again contracts, and nearly or quite disappears before the body of the comet is entirely out of sight. The tail is frequently divided into two portions, the central parts, in the direction of the axis, being less bright than the marginal parts. In 1744, a comet appeared which had six tails, spread out like a fan.

The tails of comets extend in a direct line from the sun, although more or less curved, like a long quill or feather, being convex on the side next to the direction in which they are moving a figure which may result from the less velocity of the portions most remote from the sun. Expansions of the Envelope have also been at times observed on the side next the sun, but these seldom attain any considerable length.

284. The *quantity of matter* in comets is exceedingly small. Their tails consist of matter of such tenuity that the smallest stars are visible through them. They can only be regarded as great masses of thin vapor, susceptible of being penetrated through their whole substance by

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282. Do comets shine by direct or by reflected light? Do they exhibit phases? How is it known that their light is reflected and not direct light?

283. How are the tails of comets affected by being near the sun? How many tails have some comets? In what direction is the tail in respect to the sun?

the sunbeams, and reflecting them alike from their interior parts and from their surfaces. It appears, perhaps, incredible that so thin a substance should be visible by reflected light, and some astronomers have held that the matter of comets is self-luminous; but it requires but very little light to render an object visible in the night, and a light vapor may be visible when illuminated throughout an immense stratum, which could not be seen if spread over the face of the sky like a thin cloud. From the extremely small quantity of matter of these bodies, compared with the vast spaces they cover, Newton calculated that if all the matter constituting the largest tail of a comet, were to be compressed to the same density with atmospheric air, it would occupy no more than a cubic inch. This is incredible, but still the highest clouds that float in our atmosphere, must be looked upon as dense and massive bodies, compared with the filmy and all but spiritual texture of a comet.

285. The small quantity of matter in comets is proved by the fact, that *they have sometimes passed very near to some of the planets without disturbing their motions in any appreciable degree.* Thus the comet of 1770, in its way to the sun, got entangled among the satellites of Jupiter, and remained near them four months, yet it did not perceptibly change their motions. The same comet also came very near the earth; so near, that, had its mass been equal to that of the earth, it would have caused the earth to revolve in an orbit so much larger than at present, as to have increased the length of the year, 2h. 47m. Yet it produced no sensible effect on the length of the year, and therefore its mass, as is shown by La Place, could not have exceeded $\frac{1}{5000}$ of that of the earth, and might have been less than this to any ex-

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284. How is the quantity of matter in comets? Of what do the tails consist? Can a substance so thin shine by reflected light? What opinion had Newton of the extreme tenuity of the material of comets' tails?

tent. It may indeed be asked, what proof we nave that comets have any matter, and are not mere reflections of light. The answer is, that, although they are not able by their own force of attraction to disturb the motions of the planets, yet they are themselves exceedingly disturbed by the action of the planets, and in exact conformity with the laws of universal gravitation. A delicate compass may be greatly agitated by the vicinity of a mass of iron, while the iron is not sensibly affected by the attraction of the needle.

286. By approaching very near to a large planet, a comet may have its orbit entirely changed. This fact is strikingly exemplified in the history of the comet of 1770. At its appearance in 1770, its orbit was found to be an ellipse, requiring for a complete revolution only $5\frac{1}{2}$ years; and the wonder was, that it had not been seen before, since it was a very large and bright comet. Astronomers suspected that its path had been changed, and that it had been recently compelled to move in this short ellipse, by the disturbing force of Jupiter and his satellites. The French Institute, therefore, offered a high prize for the most complete investigation of the elements of this comet, taking into account any circumstances which could possibly have produced an alteration in its course. By tracing back the movements of this comet for some years previous to 1770, it was found that, at the beginning of 1767, it had entered considerably within the sphere of Jupiter's attraction. Calculating the amount of this attraction from the known proximity of the two bodies, it was found what must have been its orbit previous to the time when it became subject to the disturbing action of Jupiter. The result showed that it then

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285. How is the small quantity of matter in comets proved How was this indicated by the comet of 1770? What did its quantity of matter not exceed as compared with the earth's? May we not infer that they have no matter?

moved in an ellipse of greater extent, having a period of 50 years, and having its *perihelion* instead of its aphelion near Jupiter. It was therefore evident why, as long as it continued to circulate in an orbit so far from the center of the system, it was never visible from the earth. In January 1767, Jupiter and the comet happened to be very near one another, and as both were moving in the same direction, and nearly in the same plane, they remained in the neighborhood of each other for several months, the planet being between the comet and the sun. The consequence was, that the comet's orbit was changed into a smaller ellipse, in which its revolution was accomplished in $5\frac{1}{2}$ years. But as it was approaching the sun in 1779, it happened again to fall in with Jupiter. It was in the month of June, that the attraction of the planet began to have a sensible effect; and it was not until the month of October following, that they were finally separated.

At the time of their nearest approach, in August, Jupiter was distant from the comet only $\frac{1}{4\frac{1}{9}\frac{1}{1}}$ of its distance from the sun, and exerted an attraction upon it 225 times greater than that of the sun. By reason of this powerful attraction, Jupiter being farther from the sun than the comet, the latter was drawn out into a new orbit, which even at its perihelion came no nearer to the sun than the planet Ceres. In this third orbit, the comet requires about 20 years to accomplish its revolution; and being at so great a distance from the earth, it is invisible, and will forever remain so, unless, in the course of ages, it may undergo new perturbations, and move again in some smaller orbit as before.

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286. How may a comet have its orbit changed? How was the orbit of the comet of 1770 changed? How was this fact ascertained? What action did Jupiter exert upon it in 1767, and again in 1779? How far was Jupiter from the comet at the time of their nearest approach? How many years does it now require to perform its revolution?

ORBITS AND MOTIONS OF COMETS.

287. The planets, as we have seen, (with the exception of the four new ones, which seem to be an intermediate class of bodies between planets and comets,) move in orbits which are nearly circular, and all very near to the plane of the ecliptic, and all move in the same direction from west to east. But the orbits of comets are far more eccentric than those of the planets; they are inclined to the ecliptic at various angles, being sometimes even nearly perpendicular to it; and the motions of comets are sometimes retrograde.

288. The *Elements* of a comet are five, viz. (1) The *perihelion distance;* (2) *longitude of the perihelion;* (3) *longitude of the node;* (4) *inclination of the orbit;* (5) *time of the perihelion passage.*

The investigation of these elements is a problem extremely intricate, requiring for its solution, a skilful and laborious application of the most refined analysis. This difficulty arises from several circumstances peculiar to comets. In the *first* place, from the elongated form of the orbits which these bodies describe, it is during only a very small portion of their course, that they are visible from the earth, and the observations made in that short period, cannot afterwards be verified on more convenient occasions; whereas in the case of the planets, whose orbits are nearly circular, and whose movements may be followed uninterruptedly throughout a complete revolution, no such impediments to the determination of their orbits occur. In the *second* place, there are many comets which move in a direction opposite to the order of the signs in the zodiac, and sometimes nearly perpendicular to the plane of the ecliptic; so that their appa-

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287. How do the orbits of comets differ from those of planets?

288. What particulars are called the elements of a comet? What is said of the difficulty of determining these elements? Specify the several reasons of this difficulty.

rent course through the heavens is rendered extremely complicated, on account of the contrary motion of the earth. In the *third* place, as there may be a multitude of elliptic orbits, whose perihelion distances are equal, (see p. 100,) it is obvious that, in the case of very eccentric orbits, the slightest change in the position of the curve near the vertex, where alone the comet can be observed, must occasion a very sensible difference in the length of the orbit; and therefore, though a small error produces no perceptible discrepancy between the observed and the calculated course, while the comet remains visible from the earth, its effect when diffused over the whole extent of the orbit, may acquire a most material or even a fatal importance.

289. On account of these circumstances, it is found exceedingly difficult to lay down the path which a comet actually follows through the whole system, and least of all, possible to ascertain with accuracy, the length of the major axis of the ellipse, and consequently the periodical revolution.* An error of only a few seconds may cause a difference of many hundred years. In this manner, though Bessel determined the revolution of the comet of 1769 to be 2089 years, it was found that an error of no more than 5″ in observation, would alter the period either to 2678 years, or to 1692. Some astronomers, in calculating the orbit of the great comet of 1680, have found the length of its greater axis 426 times the earth's distance from the sun, and consequently its period 8792 years; whilst others estimate the greater axis 430 times the earth's distance, which alters the period to 8916 years.

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289. Is it easy to ascertain the major axis of a comet's orbit, and its periodic time? What difference would an error of a few seconds occasion? Give examples of this.

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* For when we know the length of the major axis, we can find the periodic time by Kepler's law, which applies as well to comets as to planets.

Newton and Halley, however, judged that this comet accomplished its revolution in only 570 years.

290. The appearances of the same comet at different periods of its return are so various, that we can never pronounce a given comet to be the same with one that has appeared before, from any peculiarities in its physical aspect. The identity of a comet with one already on record, is determined by the identity of the elements. It was by this means that Halley first established the identity of the comet which bears his name, with one that had appeared at several preceding ages of the world, of which so many particulars were left on record, as to enable him to calculate the elements at each period. These were as in the following table.

Time of appear.	Inclin. of the orbit.	Lon. of Node.	Lon. of Per.	Per. Dist.	Course.
1456	17° 56′	48° 30′	301° 00	0.58	Retrograde
1531	17 56	49 25	301 38	0.57	"
1607	17 02	50 21	302 16	0.58	"
1682	17 42	50 48	301 36	0.58	"

On comparing these elements, no doubt could be entertained that they belonged to one and the same body; and since the interval between the successive returns was seen to be 75 or 76 years, Halley ventured to predict that it would again return in 1758. Accordingly, the astronomers who lived at that period, looked for its return with the greatest interest. It was found, however, that on its way towards the sun it would pass very near to Jupiter and Saturn, and by their action on it, it would be retarded for a long time. Clairaut, a distinguished French mathematician, undertook the laborious task of estimating the exact amount of this retardation, and found it to be no less than 618 days, namely, 100

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290. Can we identify a comet with one that has been seen before, by its appearance? How is this identity determined? How was Halley's comet proved to be the same with one that had appeared before? How was its return predicted? What causes alter the periods of its return?

days by the action of Jupiter, and 518 days by that of Saturn. This would delay its appearance until early in the year 1759, and Clairaut fixed its arrival at the perihelion within a month of April 13th. It came to the perihelion on the 12th of March.

291. The return of Halley's comet in 1835, was looked for with no less interest than in 1759. Several of the most accurate mathematicians of that age had calculated its elements with inconceivable labor. Their zeal was rewarded by the appearance of the expected visitant at the time and place assigned; it travelled the northern sky presenting the very appearances, in most respects, that had been anticipated; and came to its perihelion on the 16th of November, within two days of the time predicted by Pontecoulant, a French mathematician who had, it appeared, made the most successful calculation.* On its previous return, it was deemed an extraordinary achievement to have brought the prediction within a month of the actual time.

Many circumstances conspired to render this return of Halley's comet an astronomical event of transcendent interest. Of all the celestial bodies, its history was the most remarkable; it afforded most triumphant evidence of the truth of the doctrine of universal gravitation, and of course of the received laws of astronomy; and it inspired new confidence in the power of that instrument, (the Calculus,) by means of which its elements had been investigated.

292. Encke's comet, by its frequent returns, (once in $3\frac{1}{3}$ years,) affords peculiar facilities for ascertaining the

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291 How was the return of Halley's comet in 1835 regarded by astronomers? What circumstances conspired to produce this feeling?

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* See Professor Loomis's Observations on Halley's Comet. *Amer. Jour. Science*, 30, 209.

laws of its revolution; and it has kept the appointments made for it with great exactness. On its late return (1839) it exhibited to the telescope a globular mass of nebulous matter, resembling fog, and moved towards its perihelion with great rapidity.

But what has made Encke's comet particularly famous, is its having first revealed to us the existence of a *Resisting Medium* in the planetary spaces. It has long been a question, whether the earth and planets revolve in a perfect void, or whether a fluid of extreme rarity may not be diffused through space. A perfect vacuum was deemed most probable, because no such effects on the motions of the planets could be detected as indicated that they encountered a resisting medium. But a feather or a lock of cotton propelled with great velocity, might render obvious the resistance of a medium which would not be perceptible in the motions of a cannon ball. Accordingly, Encke's comet is thought to have plainly suffered a retardation from encountering a resisting medium in the planetary regions. The effect of this resistance, from the first discovery of the comet to the present time, has been to diminish the time of its revolution about two days. Such a resistance by destroying a part of the projectile force, would cause the comet to approach nearer to the sun, and thus to have its periodic time shortened. The ultimate effect of this cause will be to bring the comet nearer to the sun at every revolution, until it finally falls into that luminary, although many thousand years will be required to produce this catastrophe. It is conceivable, indeed, that the effects of such a resistance may be counteracted by the attraction of one or more of the planets, near which it may pass in its successive returns to the sun.

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292. Are the elements of Encke's comet calculated with exactness? What was its appearance in 1839? What has made it peculiarly famous? Why should it be so favorable for detecting a resisting medium? What has been its effect on the motions of the comet? What will be its ultimate effect?

293. It is peculiarly interesting to see a portion of matter, of a tenuity exceeding the thinnest fog, pursuing its path in space, in obedience to the same laws as those which regulate such large and heavy bodies as Jupiter or Saturn. In a perfect void, a speck of fog if propelled by a suitable projectile force, would revolve around the sun, and hold on its way through the widest orbit, with as sure and steady a pace as the heaviest and largest bodies in the system.

294. Of the *physical nature* of comets, little is understood. It is usual to account for the variations which their tails undergo, by referring them to the agencies of heat and cold. The intense heat to which they are subject in approaching so near the sun as some of them do, is alleged as a sufficient reason for the great expansion of thin nebulous atmospheres forming their tails; and the inconceivable cold to which they are subject in receding to such a distance from the sun, is supposed to account for the condensation of the same matter until it returns to its original dimensions. Thus the great comet of 1680, at its perihelion, approached 166 times nearer the sun than the earth, being only 130,000 miles from the surface of the sun. The heat which it must have received, was estimated to be equal to 28,000 times that which the earth receives in the same time, and 2000 times hotter than red hot iron. This temperature would be sufficient to volatilize the most obdurate substances, and to expand the vapor to vast dimensions; and the opposite effects of the extreme cold to which it would be

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293. Does the extreme tenuity of this body prevent its moving in obedience to the laws that regulate the motions of the largest bodies in the system?

294. Is the physical nature of comets well understood? How are the variations in the lengths of their tails accounted for? How near did the comet of 1680 approach to the sun? What heat did it acquire? Does this account for the direction of the tail? How is that accounted for by some writers?

subject in the regions remote from the sun, would be adequate to condense it into its former volume.

This explanation, however, does not account for the direction of the tail, extending as it usually does, only in a line opposite to the sun. Some writers therefore, as Delambre, suppose that the nebulous matter of the comet after being expanded to such a volume, that the particles are no longer attracted to the nucleus unless by the slightest conceivable force, are carried off in a direction from the sun, by the impulse of the solar rays themselves. But to assign such a power of communicating motion to the sun's rays while they have never been proved to have any momentum, is unphilosophical; and we are compelled to place the phenomena of comets' tails among the points of astronomy yet to be explained.

295. Since those comets which have their perihelion very near the sun, like the comet of 1680, cross the orbits of all the planets, *the possibility that one of them may strike the earth*, has frequently been suggested. Still it may quiet our apprehensions on this subject, to reflect on the vast extent of the planetary spaces, in which these bodies are not crowded together as we see them erroneously represented in orreries and diagrams, but are sparsely scattered at immense distances from each other. They are like insects flying in the expanse of heaven. If a comet's tail lay with its axis in the plane of the ecliptic when it was near the sun, we can imagine that the tail might sweep over the earth; but the tail may be situated at any angle with the ecliptic as well as in the same plane with it, and the chances

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295. What is said respecting the possibility of a comet's striking the earth? What considerations may quiet our apprehensions? How might the case be if the tail lay in the plane of the ecliptic? Is it probable that a comet will cross the ecliptic precisely at the place of the earth's path? Have comets actually approached near to the earth? What would be the consequences were a comet to strike the earth?

that it will not be in the same plane, are almost infinite. It is also extremely improbable that a comet will cross the plane of the ecliptic precisely at the earth's path in that plane, since it may as probably cross it at any other point, nearer or more remote from the sun. Still some comets have occasionally approached near to the earth. Thus Biela's comet in returning to the sun in 1832, crossed the ecliptic very near to the earth's track, and had the earth been then at that point of its orbit, it might have passed through a portion of the nebulous atmosphere of the comet. The earth was within a month of reaching that point. This might at first view seem to involve some hazard; yet we must consider that a month short, implied a distance of nearly 50,000,000 miles. La Place has assigned the consequences that would ensue in case of a direct collision between the earth and a comet; but terrible as he has represented them on the supposition that the nucleus of the comet is a solid body, yet considering a comet (as most of them doubtless are) as a mass of exceedingly light nebulous matter, it is not probable, even were the earth to make its way directly through a comet, that a particle of the comet would reach the earth. The portions encountered by the earth, would be arrested by the atmosphere, and probably inflamed; and they would perhaps exhibit, on a more magnificent scale than was ever before observed, the phenomena of shooting stars, or meteoric showers.

PART III.—OF THE FIXED STARS AND THE SYSTEM OF THE WORLD.

CHAPTER I.

OF THE FIXED STARS—CONSTELLATIONS.

296. The Fixed Stars are so called, because, to common observation, they always maintain the same situations with respect to one another.

The stars are classed by their apparent *magnitudes*. The whole number of magnitudes recorded are *sixteen*, of which the first six only are visible to the naked eye; the rest are *telescopic stars*. These magnitudes are not determined by any very definite scale, but are merely ranked according to their relative degrees of brightness, and this is left in a great measure to the decision of the eye alone. The brightest stars to the number of 15 or 20, are considered as stars of the *first* magnitude; the 50 or 60 next brightest, of the *second* magnitude; the next 200 of the *third* magnitude; and thus the number of each class increases rapidly as we descend the scale, so that no less than fifteen or twenty thousand are included within the first seven magnitudes.

297. The stars have been grouped in *Constellations* from the most remote antiquity; a few, as Orion, Bootes, and Ursa Major, are mentioned in the most ancient writings under the same names as they bear at present. The names of the constellations are sometimes founded

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296. *Fixed Stars.*—Why so called? How classed? Into how many magnitudes are they divided? How many are there of each magnitude?

on a supposed resemblance to the objects to which the names belong; as the Swan and the Scorpion were evidently so denominated from their likeness to those animals; but in most cases it is impossible for us to find any reason for designating a constellation by the figure of the animal or the hero which is employed to represent it. These representations were probably once blended with the fables of pagan mythology. The same figures, absurd as they appear, are still retained for the convenience of reference; since it is easy to find any particular star, by specifying the part of the figure to which it belongs, as when we say a star is in the neck of Taurus, in the knee of Hercules, or in the tail of the Great Bear. This method furnishes a general clue to its position; but the stars belonging to any constellation are distinguished according to their apparent magnitudes as follows:—first, by the Greek letters, Alpha, Beta, Gamma, &c. Thus *Alpha Orionis*, denotes the largest star in Orion; *Beta Andromedæ*, the second star in Andromeda; and *Gamma Leonis*, the third brightest star in the Lion. Where the number of the Greek letters is insufficient to include all the stars in a constellation, recourse is had to the letters of the Roman alphabet, a, b, c, &c.; and, in cases where these are exhausted, the final resort is to numbers. This is evidently necessary, since the largest constellations contain many hundrerds or even thousands of stars. *Catalogues* of particular stars have also been published by different astronomers, each author numbering the individual stars embraced in his list, according to the places they respectively occupy in the catalogue. These references to particular catalogues are sometimes entered on large celestial globes. Thus we meet with a star marked 84 H., meaning that

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297. *Constellations.*—How long known? Which are mentioned in the most ancient writings? How far are the names founded on resemblance? Why are the ancient figures still retained? How are the individual stars of a constellation distinguished? What is said of catalogues of the stars?

this is its number in Herschel's catalogue; or 140 M., denoting the place the star occupies in the catalogue of Mayer.

298. The earliest catalogue of the stars was made by Hipparchus of the Alexandrian school, about 140 years before the Christian era. A new star appearing in the firmament, he was induced to count the stars and to record their positions, in order that posterity might be able to judge of the permanency of the constellations. His catalogue contains all that were conspicuous to the naked eye in the latitude of Alexandria, being 1022. Most persons unacquainted with the actual number of the stars which compose the visible firmament, would suppose it to be much greater than this; but it is found that the catalogue of Hipparchus, embraces nearly all that can now be seen in the same latitude, and that on the equator, when the spectator has the northern and southern hemispheres both in view, the number of stars that can be counted does not exceed 3000. A careless view of the firmament in a clear night, gives us the impression of an infinite multitude of stars; but when we begin to count them, they appear much more sparsely distributed than we supposed, and large portions of the sky appear almost destitute of stars.

By the aid of the telescope, new fields of stars present themselves of boundless extent; the number continually augmenting as the powers of the telescope are increased. Lalande, in his Histoire Celeste, has registered the positions of no less than 50,000; and the whole number visible in the largest telescopes amounts to many millions.

299. It is strongly recommended to the learner to acquaint himself with the leading constellations at least,

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298. Why did Hipparchus make a catalogue? How many stars did he number? What is the greatest number that can be seen by the naked eye in both hemispheres? How many can be seen by the telescope?

and with a few of the most remarkable individual stars. The task of learning them is comparatively easy, and hardly any kind of knowledge, attained with so little labor, so amply rewards the possessor. It will generally be advisable, at the outset, to get some one already acquainted with the stars, to point out a few of the most conspicuous constellations, those of the Zodiac for example; the learner may then resort to maps of the stars, or what is much better, to a celestial globe,* and fill up the outline by tracing out the principal stars in each constellation as there laid down. By adding one new constellation to his list every night, and reviewing those already acquired, he will soon become familiar with the stars, and will greatly augment his interest and improve his intelligence in celestial observations, and practical astronomy.

CONSTELLATIONS.

300. We will point out particular marks by which the leading constellations may be recognized, leaving it to the learner, after he has found a constellation, to trace out additional members of it by the aid of the celestial globe, or by maps of the stars. Let us begin with the *Constellations of the Zodiac*, which succeeding each other as they do in a known order, are most easily found.

Aries (The Ram) is a small constellation, known by two bright stars which form his head, *Alpha* and *Beta Arietis*. These two stars are four degrees† apart, and directly south of *Beta* at the distance of one degree, is

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299. Specify the directions for learning the constellations.

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* For the method of rectifying the globe so as to represent the appearance of the heavens on any particular evening, see page 34, Art. 61.

† These measures are not intended to be stated with exactness, but only with such a degree of accuracy as may serve for a general guide.

a smaller star, *Gamma Arietis*. It has been already intimated (Art. 139) that the vernal equinox probably was near the head of Aries, when the signs of the Zodiac received their present names.

TAURUS (The BULL) will be readily found by the seven stars or *Pleiades*, which lie in his neck. The largest star in Taurus is *Aldebaran*, in the Bull's eye, a star of the first magnitude, of a reddish color somewhat resembling the planet Mars. Aldebaran and four other stars in the face of Taurus, compose the *Hyades*.

GEMINI (The TWINS) is known by two very bright stars, Castor and Pollux, four degrees asunder. Castor (the northern) is of the first, and Pollux of the second magnitude.

CANCER (The CRAB.) There are no large stars in this constellation, and it is regarded as less remarkable than any other in the Zodiac. It contains however an interesting group of small stars, called *Præsepe* or the Nebula of Cancer, which resembles a comet, and is often mistaken for one, by persons unacquainted with the stars. With a telescope of very moderate powers this nebula is converted into a beautiful assemblage of exceedingly bright stars.

LEO (The LION) is a very large constellation, and has many interesting members. *Regulus* (*Alpha Leonis*) is a star of the first magnitude, which lies directly in the ecliptic, and is much used in astronomical observations.

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300. Constellations of the Zodiac.—*Aries*.—How known? How far are the two brightest stars apart? Where was the vernal equinox situated when the signs of the Zodiac received their present names?

Taurus.—How found? Name the largest star in Taurus. What stars compose the Hyades?

Gemini.—How known? How far are Castor and Pollux asunder? Of what magnitudes are they respectively?

Cancer.—Are there any large stars in Cancer? What is said of Præsepe?

Leo.—What is its size? What is said of Regulus? Where is the sickle? Where is Denebola situated?

North of Regulus lies a semi-circle of bright stars, forming a *sickle* of which Regulus is the handle. *Denebola*, a star of the second magnitude, is in the Lion's tail, 25° north east of Regulus.

Virgo (The Virgin) extends a considerable way from west to east, but contains only a few bright stars. *Spica*, however, is a star of the first magnitude, and lies a little east of the place of the autumnal equinox. Twenty-two degrees north of Spica, is *Vindemiatrix*, in the arm of Virgo, a star of the third magnitude.

Libra (The Balance) is distinguished by three large stars, of which the two brightest constitute the beam of the balance, and the smallest forms the top or handle.

Scorpio (The Scorpion) is one of the finest of the constellations. His head is formed of five bright stars arranged in the arc of a circle, which is crossed in the center by the ecliptic nearly at right angles, near the brightest of the five, *Beta Scorpionis*. Nine degrees southeast of this, is a remarkable star of the first magnitude, of a reddish color, called *Cor Scorpionis*, or *Antares*. South of this a succession of bright stars sweep round towards the east, terminating in several small stars, forming the tail of the Scorpion.

Sagittarius (The Archer.) Northeast of the tail of the Scorpion, are three stars in the arc of a circle which constitute the *bow* of the Archer, the central star being the brightest, directly west of which is a bright star which forms the *arrow*.

Capricornus (The Goat) lies northeast of Sagittarius, and is known by two bright stars, three degrees apart, which form the head.

Virgo.—Extent from east to west? What is said of Spica, and of Vindemiatrix?

Libra.—How distinguished?

Scorpio.—His appearance? His head how formed? Where is Antares situated?

Sagittarius.—Describe his bow.

Capricornus.—Where situated from Sagittarius? How known?

AQUARIUS (The WATER BEARER) is recognized by two stars in a line with *Alpha Capricorni*, forming the shoulders of the figure. These two stars are 10° apart, and 4° southeast is a third star, which, together with the other two, makes an acute triangle, of which the westernmost is the vertex.

PISCES (The FISHES) lie between Aquarius and Aries. They are not distinguished by any large stars, but are connected by a series of small stars, that form a crooked line between them. *Piscis Australis*, the Southern Fish, lies directly below Aquarius, and is known by a single bright star far in the south, having a declination of 30°. The name of this star is *Fomalhaut*, and it is much used in astronomical measurements.

301. The Constellations of the Zodiac, being first well learned, so as to be easily recognized, will facilitate the learning of others that lie north and south of them. Let us therefore next review the principal *Northern Constellations*, beginning north of Aries and proceeding from west to east.

ANDROMEDA, is characterized by three stars of the second magnitude, situated in a straight line, extending from west to east. The middle star is about 17° north of *Beta Arietis*. It is in the girdle of Andromeda, and is named *Mirach*. The other two lie at about equal distances, 14° west and east of Mirach. The western star, in the head of Andromeda, lies in the Equinoctial Colure. The eastern star, *Alamak*, is situated in the foot.

PERSEUS lies directly north of the Pleiades, and contains several bright stars. About 18° from the Pleiades

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Aquarius.—How recognized? How far apart are the shoulders of Aquarius?

Pisces.—Where situated? How connected? Where is Piscis Australis situated? By what name is it commonly known?

301 Northern Constellations. *Andromeda*, how characterized? Where are Mirach and Alamak situated?

is *Algol*, a star of the second magnitude in the Head of Medusa, which forms a part of the figure; and 9° northeast of Algol is *Algenib*, of the same magnitude in the back of Perseus. Between Algenib and the Pleiades are three bright stars, at nearly equal intervals, which compose the right leg of Perseus.

Auriga (the Wagoner) lies directly east of Perseus, and extends nearly parallel to that constellation from north to south. *Capella* a very white and beautiful star of the first magnitude, distinguishes this constellation. The feet of Auriga are near the Bull's Horns.

The Lynx comes next, but presents nothing particularly interesting, containing no stars above the fourth magnitude.

Leo Minor consists of a collection of small stars north of the sickle in Leo, and south of the Great Bear. Its largest star is only of the third magnitude.

Coma Berenices is a cluster of small stars, north of Denebola, (a star in the tail of the Lion,) and of the head of Virgo. About 12° north of Berenice's Hair, is a single bright star called *Cor Caroli*, or Charles's Heart.

Bootes, which comes next, is easily found by means of *Arcturus*, a star of the first magnitude, of a reddish color, which is situated near the knee of the figure. Arcturus is accompanied by three small stars forming a triangle a little to the southwest. Two bright stars *Gamma* and *Delta Bootis*, form the shoulders, and *Beta* of the third magnitude is in the head of the figure.

Corona Borealis, (The Crown,) which is situated east

Perseus.—How situated with respect to the Pleiades? Where is Algol? Where is Algenib? What stars compose the right leg of Perseus?

Auriga.—How situated from Perseus? What large star distinguishes this constellation? Where are the feet of Auriga?

Lynx.—Size of its stars?

Leo Minor.—Where situated? Size of its largest star?

Coma Berenices.—Describe it. Where is Cor Caroli?

Bootes.—What large star is in this constellation?

of Bootes, is very easily recognized, composed as it is of a semi-circle of bright stars. In the center of the bright crown, is a star of the second magnitude, called *Gemma;* the remaining stars are all much smaller.

HERCULES, lying between the Crown on the west and the Lyre on the east, is very thick set with stars, most of which are quite small. The Constellation covers a great extent of the sky, especially from N. to S., the head terminating within 15° of the equator, and marked by a star of the third magnitude, called *Ras Algethi*, which is the largest in the Constellation.

OPHIUCUS is situated directly south of Hercules, extending some distance on both sides of the equator, the feet resting on the Scorpion. The head terminates near the head of Hercules, and like that, is marked by a bright star within 5° of *Alpha Herculis*. Ophiucus is represented as holding in his hands the SERPENT, the head of which, consisting of three bright stars, is situated a little south of the Crown. The folds of the serpent will be easily followed by a succession of bright stars which extend a great way to the east.

AQUILA (The EAGLE) is conspicuous for three bright stars in its neck, of which the central one, *Altair*, is a very brilliant white star of the first magnitude. *Antinous* lies directly south of the Eagle, and north of the head of Capricornus.

DELPHINUS (The DOLPHIN) is a small but beautiful Constellation, a few degrees east of the Eagle, and is characterized by four bright stars near to one another, forming a small rhombic square. Another star of the same magnitude 5° south, makes the tail.

Corona Borealis.—Describe it. Where is Gemma situated?

Hercules.—Between what two constellations is it? What is said of its extent? Where is Ras Algethi?

Ophiucus.—Where is it from Hercules? How is it represented?

Aquila.—How distinguished? Where is Altair? Where is Antinous?

The *Dolphin*.—Describe it.

Pegasus lies between Aquarius on the southwest and Andromeda on the northeast. It contains but few large stars. A very regular square of bright stars is composed of *Alpha Andromedæ*, and the three largest stars in Pegasus, namely, *Scheat*, *Markab*, and *Algenib*. The sides composing this square are each about 15°. Algenib is situated in the Equinoctial Colure.

302. We may now review the *Constellations which surround the North Pole*, within the circle of perpetual apparition. (Art. 38.)

Ursa Minor (The Little Bear) lies nearest the pole. The Pole-star, *Polaris*, is in the extremity of the tail, and is of the third magnitude. Three stars in a straight line 4° or 5° apart, commencing with the Pole-star, lead to a trapezium of four stars, and the whole seven form together a *dipper*, the trapezium being the body, and the three stars the handle.

Ursa Major (The Great Bear) is situated between the pole and the Lesser Lion, and is usually recognized by the figure of a larger and more perfect dipper, which constitutes the hinder part of the animal. This has also seven stars, four in the body of the dipper, and three in the handle. All these are stars of much celebrity. The two in the western side of the dipper, Alpha and Beta, are called *Pointers*, on account of their always being in a right line with the Pole-star, and therefore affording an easy mode of finding that. The first star in the tail, next the body, is named *Alioth*, and the second *Mizar*. The head of the Great Bear lies far to the westward of the

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Pegasus.—Between what two constellations is it situated? How may a square be formed of certain stars in this constellation?

302. Northern Constellations. *Ursa Minor.*—How situated with respect to the pole? Show how the dipper in this constellation is formed?

Ursa Major.—Where situated? How recognized? What are the Pointers? Where is Alioth—Mizar? Of what is the head composed?

Pointers, and is composed of numerous small stars; and the feet are severally composed of two small stars very near to each other.

Draco (The Dragon) winds round between the Great and the Little Bear; and commencing with the tail, between the Pointers and the Pole-star, it is easily traced by a succession of bright stars extending from west to east, passing under Ursa Minor, it returns westward, and terminates in a triangle which forms the head of Draco, near the feet of Hercules, northwest of Lyra.

Cepheus lies eastward of the breast of the Dragon, but has no stars above the third magnitude.

Cassiopeia is known by the figure of a *chair*, composed of four stars which form the legs, and two which form the back. This constellation lies between Perseus and Cepheus, in the Milky Way.

Cygnus (The Swan) is situated also in the Milky Way, some distance southwest of Cassiopeia, towards the Eagle. Three bright stars, which lie along the Milky Way, form the body and neck of the Swan, and two others in a line with the middle one of the three, one above and one below, constitute the wings. This Constellation is among the few, that exhibit some resemblance to the animals whose names they bear.

Lyra (The Lyre) is directly west of the Swan, and is easily distinguished by a beautiful white star of the first magnitude, *Alpha Lyræ*.

303. The *Southern Constellations* are comparatively few in number. We shall notice only the Whale, Orion, the Greater and Lesser Dog, Hydra, and the Crow.

Draco.—How situated with respect to the two Bears? Trace its course?

Cepheus.—How situated from Draco?

Cassiopeia.—How known? Where situated?

Cygnus.—How situated? Of what stars formed? Has this constellation any resemblance to a Swan?

303. Southern Constellations. *Cetus.*—Its extent? Size of its stars? What is said of Menkar, and of Mira?

Cetus (The Whale) is distinguished rather for its extent than its brilliancy, reaching as it does through 40° of longitude, while none of its stars except one, are above the third magnitude. *Menkar* (*Alpha* Ceti) in the mouth, is a star of the second magnitude, and several other bright stars directly south of Aries, make the head and neck of the Whale. *Mira* (*Omicron Ceti*) in the neck of the Whale is a variable star.

Orion is one of the largest and most beautiful of the constellations, lying southeast of Taurus. A cluster of small stars form the head; two large stars, *Betalgeus* of the first and *Bellatrix* of the second magnitude, make the shoulders; three more bright stars compose the buckler, and three the sword; and *Rigel*, another star of the first magnitude, makes one of the feet. In this Constellation there are 70 stars plainly visible to the naked eye, including two of the first magnitude, four of the second, and three of the third.

Canis Major lies S. E. of Orion, and is distinguished chiefly by its containing the largest of the fixed stars, *Sirius*.

Canis Minor a little north of the equator, between Canis Major and Gemini, is a small Constellation, consisting chiefly of two stars, of which *Procyon* is of the first magnitude.

Hydra has its head near Procyon, consisting of a number of stars of ordinary brightness. About 17° S. E. of the head, is a star of the second magnitude, forming the heart, (*Cor Hydræ;*) and eastward of this, is a long succession of stars of the fourth and fifth magnitudes composing the body and the tail, and reaching a few degrees south of Spica Virginis.

Orion.—What is said of its size and beauty? Describe its different parts. How many stars does it contain which are visible to the naked eye?

Canis Major.—Where situated from Orion? What large star is in it?

Canis Minor.—Where situated? What large star does it contain?

Hydra.—Trace its course.

Corvus (The Crow) is represented as standing on the tail of Hydra. It consists of small stars, only three of which are as large as the third magnitude.

304. The foregoing brief sketch is designed merely to aid the student in *finding* the principal constellations and the largest fixed stars. When we have once learned to recognize a constellation by some characteristic marks, we may afterwards fill up the outline by the aid of a celestial globe or a map of the stars. It will be of little avail however, merely to commit this sketch to memory; but it will be very useful for the student at once to render himself familiar with it, from the actual specimens which every clear evening presents to his view.

CHAPTER II.

OF CLUSTERS OF STARS—NEBULÆ—VARIABLE STARS—TEMPORARY STARS—DOUBLE STARS.

305. In various parts of the firmament are seen large groups or *clusters*, which, either by the naked eye, or by the aid of the smallest telescope, are perceived to consist of a great number of small stars. Such are the Pleiades, Coma Berenices, and Præsepe or the Bee-hive in Cancer. The Pleiades, or *Seven stars*, as they are called, in the neck of Taurus, is the most conspicuous cluster. When we look *directly* at this group, we cannot distinguish more than six stars, but by turning the eye *sideways** upon it, we discover that there are many

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Corvus.—How represented?

305. *Clusters.*—Name a few of the largest. Pleiades, where situated? How many stars does it contain? What is said of Coma Berenices, and of the Bee-hive?

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* Indirect vision is far more delicate than direct. Thus we can see the Zodiacal Light or a Comet's Tail, much more distinctly and better defined, if we fix one eye on a part of the heavens at some distance, and turn the other eye obliquely upon the object.

more. Telescopes show 50 or 60 stars crowded together and apparently insulated from the other parts of the heavens. Coma Berenices has fewer stars, but they are of a larger class than those which compose the Pleiades. The Bee-hive or Nebula of Cancer as it is called, is one of the finest objects of this kind for a small telescope, being by its aid converted into a rich congeries of shining points. The head of Orion affords an example of another cluster, though less remarkable than the others.

306. *Nebulæ* are those faint misty appearances which resemble comets, or a small speck of fog. The Galaxy or Milky Way, presents a continued succession of large nebulæ. A very remarkable Nebula, visible to the naked eye, is seen in the girdle of Andromeda. No powers of the telescope have been able to resolve this into separate stars. Its dimensions are astonishingly great. In diameter it is about 15′. The telescope reveals to us innumerable objects of this kind. Sir William Herschel has given catalogues of 2000 Nebulæ, and has shown that the nebulous matter is distributed through the immensity of space in quantities inconveivably great, and in separate parcels of all shapes and sizes, and of all degrees of brightness between a mere milky appearance and the condensed light of a fixed star. Finding that the gradations between the two extremes were tolerably regular, he thought it probable that the nebulæ form the materials out of which nature elaborates suns and systems; and he conceived that, in virtue of a central gravitation, each parcel of nebulous matter becomes more and more condensed, and assumes a rounded form. He inferred from the eccentricity of its shape, and the effects of the mutual gravitation of its particles, that it acquires gradu-

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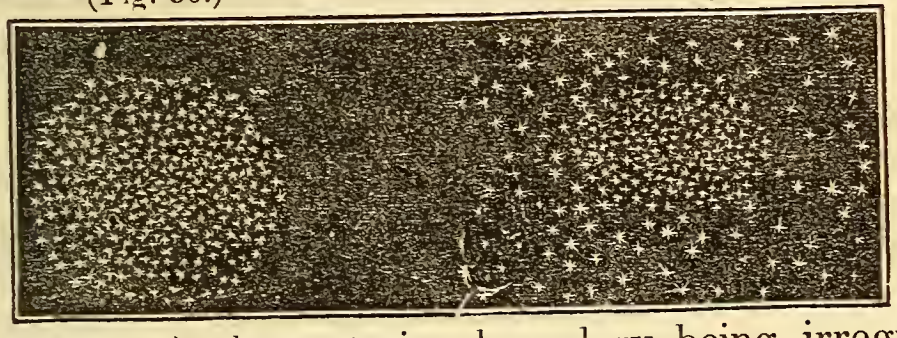
306. *Nebulæ.*—What are they? What is said of the nebula in the girdle of Andromeda? How many nebulæ has Sir W. Herschel included in his catalogue? What are his ideas respecting nebulæ?

ally a rotary motion; that the condensation goes on increasing until the mass acquires consistency and solidity and all the characters of a comet or a planet; that by a still further process of condensation, the body becomes a real star, self-shining; and that thus the waste of the celestial bodies, by the perpetual diffusion of their light, is continually compensated and restored by new formations of such bodies, to replenish forever the universe with planets and stars.

307. These opinions are recited here rather out of respect to their notoriety and celebrity, than because we suppose them to be founded on any better evidence than conjecture. The Philosophical Transactions for many years, both before and after the commencement of the present century, abound with both the observations and speculations of Sir William Herschel. The former are deserving of all praise; the latter of much less confidence. Changes, however, are going on in some of the nebulæ, which plainly show that they are not, like planets and stars, fixed and permanent creations. Thus the great nebula in the girdle of Andromeda, has very much altered its structure since it first became an object of telescopic observation. Many of the nebulæ are of a globular form, (Fig. 50,) but frequently they present the appearance of a rapid increase of numbers towards the center, (Fig. 51,) the anterior boundary being irregular, and the central parts more nearly spherical.

(Fig. 50.) (Fig. 51.)



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307. What is said of Herschel's speculations and of his observations? What changes occur in the nebulæ? What forms have they?

308. The nebula in the sword of Orion is particularly celebrated, being very large and of a peculiarly interesting appearance. According to Sir John Herschel, its nebulous character is very different from what might be supposed to arise from the assemblage of an immense collection of small stars. It is formed of little flocculent masses like wisps of clouds; and such wisps seem to adhere to many small stars at its outskirts, and especially to one considerable star which it envelops with a nebulous atmosphere of considerable extent and singular figure.

Descriptions, however, can convey but a very imperfect idea of this wonderful class of astronomical objects, and we would therefore urge the learner studiously to avail himself of the first opportunity he may have to view them through a large telescope, especially the Nebula of Andromeda and of Orion.

309. *Nebulous Stars* are such as exhibit a sharp and brilliant star surrounded by a disk or atmosphere of nebulous matter. These atmospheres in some cases present a circular, in others an oval figure; and in some instances, the nebula consists of a long, narrow spindle-shaped ray, tapering away at both ends to points.

Planetary Nebulæ constitute another variety, and are very remarkable objects. They have, as their name imports, exactly the appearance of planets. Whatever may be their nature, they must be of enormous magnitude. One of them is to be found in the parallel of Gamma Aquarii, and about 5m. preceding that star. Its apparent diameter is about 20″. Another in the Constellation Andromeda, presents a visible disk of 12″, perfectly defined and round. Granting these objects to be

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308. What is said of the nebula in the sword of Orion? Can the nebulæ be fully learned from description?

309. Nebulous stars—what are they? What forms have their atmospheres? Planetary nebulæ,—their appearance? What apparent diameters have they? What is said of their light?

equally distant from us with the stars, their real dimensions must be such as, on the lowest computation, would fill the orbit of Uranus. It is no less evident that, if they be solid bodies, of a solar nature, the intrinsic splendor of their surfaces must be almost infinitely inferior to that of the sun. A circular portion of the sun's disk, subtending an angle of 20″, would give a light equal to 100 full moons; while the objects in question are hardly, if at all, discernible with the naked eye.

310. The *Galaxy* or *Milky Way* is itself supposed by some to be a nebula of which the sun forms a component part; and hence it appears so much greater than other nebulæ only in consequence of our situation with respect to it, and its greater proximity to our system. So crowded are the stars in some parts of this zone, that Sir William Herschel, by counting the stars in a single field of his telescope, estimated that 50,000 had passed under his review in a zone two degrees in breadth during a single hour's observation. Notwithstanding the apparent contiguity of the stars which crowd the galaxy, it is certain that their mutual distances must be inconceivably great.

311. Variable Stars are those which undergo a periodical change of brightness. One of the most remarkable is the star *Mira* in the Whale, (*Omicron Ceti.*) It appears once in 11 months, remains at its greatest brightness about a fortnight, being then, on some occasions, equal to a star of the second magnitude. It then decreases about three months, until it becomes completely invisible, and remains so about five months, when it again becomes visible, and continues increasing during the remaining three months of its period.

Another very remarkable variable star is *Algol* (Beta Persei.) It is usually visible as a star of the second magni-

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310. Galaxy or Milky Way—what is said respecting it? Give an example of the multitude of stars in it?

tude, and continues such for 2d. 14h. when it suddenly begins to diminish in splendor, and in about $3\frac{1}{2}$ hours is reduced to the fourth magnitude. It then begins again to increase, and in $3\frac{1}{2}$ hours more, is restored to its usual brightness, going through all its changes in less than three days. This remarkable law of variation appears strongly to suggest the revolution round it of some opake body, which, when interposed between us and Algol, cuts off a large portion of its light. It is (says Sir J. Herschel) an indication of a high degree of activity in regions where, but for such evidences, we might conclude all lifeless. Our sun requires almost nine times this period to perform a revolution on its axis. On the other hand, the periodic time of an opake revolving body, sufficiently large, which would produce a similar temporary obscuration of the sun, seen from a fixed star, would be less than fourteen hours.

The duration of these periods is extremely various. While that of Beta Persei above mentioned, is less than three days, others are more than a year, and others many years.

312. Temporary Stars are new stars which have appeared suddenly in the firmament, and after a certain interval, as suddenly disappeared and returned no more.

It was the appearance of a new star of this kind 125 years before the Christian era, that prompted Hipparchus to draw up a catalogue of the stars, the first on record. Such also was the star which suddenly shone out A. D 389, in the Eagle, as bright as Venus, and after remaining three weeks disappeared entirely. At other periods, at distant intervals, similar phenomena have presented themselves. Thus the appearance of a star in 1572, was so sudden, that Tycho Brahe returning home one

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311. Variable stars—what are they? What is said of Mira? Also of Algol? How are their periods of revolution?

312. Temporary stars—what are they? Give examples. Do they ever return? Do stars ever disappear?

day was surprized to find a collection of country people gazing at a star which he was sure did not exist half an hour before. It was then as bright as Sirius, and continued to increase until it surpassed Jupiter when brightest, and was visible at mid-day. In a month it began to diminish, and in three months afterwards it had entirely disappeared.

It has been supposed by some that in a few instances, the same star has returned, constituting one of the periodical or variable stars of a long period.

Moreover, on a careful re-examination of the heavens, and a comparison of catalogues, many stars are now found to be missing.

313. Double Stars are those which appear single to the naked eye, but are resolved into two by the telescope; or, if not visible to the naked eye, are seen in the telescope so close together as to be recognized as objects of this class. Sometimes three or more stars are found in this near connexion, constituting *triple* or *multiple* stars. Castor, for example, when seen by the naked eye, appears as a single star, but in a telescope even of moderate powers, it is resolved into two stars of between the third and fourth magnitudes, within 5″ of each other. These two stars are nearly of equal size, but frequently one is exceedingly small in comparison with the other, resembling a satellite near its primary, although in distance, in light, and in other characteristics, each has all the attributes of a star, and the combination therefore cannot be that of a planet with a satellite. In some instances, also, the distance between these objects is much less than 5″, and in many cases it is less than 1″. The extreme closeness, together with the exceeding minuteness of most of the double stars, requires the best tele-

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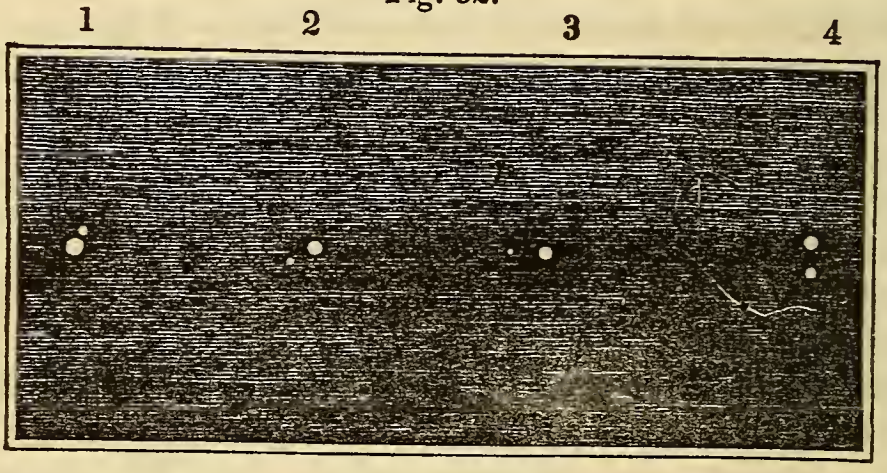
313. Double stars—what are they? What are multiple stars? Give an example of a double star? How do the two stars sometimes differ? What is required in order to observe most of the double stars?

scopes united with the most acute powers of observation. Indeed, certain of these objects are regarded as the severest *tests*, both of the excellence of the instrument and of the skill of the observer. The following diagram represents four double stars, as seen with appropriate magnifiers. No. 1. exhibits Epsilon Bootis with a power of 350; No. 2, Rigel with a power of 130; No. 3, the Pole-star with a power of 100; and No. 4, Castor with a power of 300.

Fig. 52.



314. Our knowledge of the double stars almost commenced with Sir William Herschel, about the year 1780. At the time he began his search for them, he was acquainted with only *four*. Within five years, he discovered nearly 700 double stars.* In his memoirs, published in the Philosophical Transactions, he gave most accurate measurements of the distances between the two stars, and of the angle which a line joining the two, formed with the parallel of declination. These data would enable him, or at least posterity, to judge whether these minute bodies ever change their position with respect to each other.

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314. Who began the discovery of double stars? When did he publish his account of them? By whom have these researches been since prosecuted? What two circumstances add a high degree of interest to the phenomena of the double stars?

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* During his life he observed in all, 2400 double stars.

Since 1821, these researches have been prosecuted with great zeal and industry by Sir James South and Sir John Herschel in England, and by Professor Struve at Dorpat in Russia; and the whole number of double stars now known, amounts to several thousands. Two circumstances add a high degree of interest to the phenomena of the double stars—the first is, that a few of them at least are found to have a revolution around each other, and the second, that they are supposed to afford the means of obtaining the parallax of the fixed stars. Of these topics we shall treat in the next chapter.

CHAPTER III.

OF THE MOTIONS OF THE FIXED STARS—DISTANCES—NATURE.

315. In 1803, Sir William Herschel first determined and announced to the world, that there exist among the stars, separate systems, composed of two stars revolving about each other in regular orbits. These he denominated *Binary Stars*, to distinguish them from other double stars where no such motion is detected, and whose proximity to each other may possibly arise from casual juxta-position, or from one being in the range of the other. Between fifty and sixty instances of changes to a greater or less amount of the relative position of double stars, are mentioned by Sir William Herschel; and a few of them had changed their places so much within 25 years, and in such order, as to lead him to the conclusion that they performed revolutions, one around the other, in regular orbits.

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315. *Binary Stars.*—Who first discovered this class of bodies? How are they distinguished from ordinary double stars? What conclusions did Sir W. Herschel draw respecting them?

316. These conclusions have been fully confirmed by later observers, so that it is now considered as fully established, that there exist among the fixed stars, binary systems, in which two stars perform to each other the office of sun and planet, and that the periods of revolution of more than one such pair have been ascertained with something approaching to exactness. Immersions and emersions of stars behind each other have been observed, and real motions among them detected rapid enough to become sensible and measurable in very short intervals of time. The following table exhibits the present state of our knowledge on this subject.*

Names.	Period in years.	Major axis of the orbit.	Eccentricity.
ηCoronæ,	43.40	———	———
ζCancri,	55.00	———	———
ξUrsæ Majoris,	58.26	7″.714	0.4164
70 Ophiuchi	80.34	8.784	0.4667
Castor,	252.66	16.172	0.7582
σCoronæ,	286.00	7.358	0.6112
61 Cygni,	452.00	30.860	———
γVirginis,	628.90	24.000	0.8335
γLeonis,	1200.00	———	———

From this table it appears, first, that the periods of the double stars are very various, ranging, in the case of those already ascertained, from forty-three years to one

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316. Have the conclusions of Herschel been confirmed by others? What doctrine is now considered as fully established? How are the periods of the double stars? What is the figure of their orbits? Which is the most remarkable of the Binary stars? What is its size? How long since it was first observed to be double? What changes has it undergone since? When did it pass its perihelion?

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* Those who do not understand the Greek letters, can pass over this table to the inferences which follow.

thousand; secondly, that their orbits are very small ellipses, more eccentric than those of the planets, the greatest of which (that of Mercury) having an eccentricity of only about .2 of the major axis.

The most remarkable of the binary stars is Gamma Virginis, on account not only of the length of its period, but also of the great diminution of apparent distance, and rapid increase of angular motion about each other of the individuals composing it. It is a bright star of the fourth magnitude, and its component stars are almost exactly equal. It has been known to consist of two stars since the beginning of the eighteenth century, their distance being then between six and seven seconds; so that any tolerably good telescope would resolve it. Since that time they have been constantly approaching, and are at present hardly more than a single second asunder; so that no telescope that is not of a very superior quality, is competent to show them otherwise than as a single star, somewhat lengthened in one direction. It fortunately happens that Bradley (Astronomer Royal) in 1718, noticed, and recorded in the margin of one of his observation books, the apparent direction of their line of junction, as being parallel to that of two remarkable stars Alpha and Delta of the same constellation, as seen by the naked eye,—a remark which has been of signal service in the investigation of their orbit. It is found that it passed its perihelion, August 18th, 1834.

317. The revolutions of the binary stars have assured us of that most interesting fact, that *the law of gravitation extends to the fixed stars.* Before these discoveries, we could not decide except by a feeble analogy that this law transcended the bounds of the solar system. In-

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17. What great fact have the revolutions of the binary stars revealed to us? How was this doctrine limited before this discovery? Are these revolutions those of a planetary or cometary nature?

deed, our belief of the fact rested more upon our idea of unity of design in all the works of the Creator, than upon any certain proof; but the revolution of one star around another in obedience to forces which must be similar to those that govern the solar system, establishes the grand conclusion, that the law of gravitation is truly the law of the material universe.

We have the same evidence (says Sir John Herschel) of the revolutions of the binary stars about each other, that we have of those of Saturn and Uranus about the sun; and the correspondence between their calculated and observed places in such elongated ellipses, must be admitted to carry with it a proof of the prevalence of the Newtonian law of gravity in their systems, of the very same nature and cogency as that of the calculated and observed places of comets round the center of our own system.

But (he adds) it is not with the revolution of bodies of a planetary or cometary nature round a solar center that we are now concerned; it is with that of sun around sun, each, perhaps, accompanied with its train of planets and their satellites, closely shrouded from our view by the splendor of their respective suns, and crowded into a space, bearing hardly a greater proportion to the enormous interval which separates them, than the distances of the satellites of our planets from their primaries, bear to their distances from the sun itself.

318. *Some of the fixed stars appear to have a real motion in space.*

There are several *apparent* changes of place among the stars which arise from real changes in the earth, which, as we are not conscious of them, we refer to the stars; but there are other motions among the stars which

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318. Have any of the fixed stars a real motion in space? Are the places of the stars as described in ancient times by Ptolemy nearly the same as at present? To what conclusions on this subject are we now forced?

cannot result from any changes in the earth, but must arise from changes in the stars themselves. Such motions are called the *proper motions* of the stars. Nearly 2000 years ago, Hipparchus and Ptolemy made the most accurate determinations in their power of the relative situations of the stars, and their observations have been transmitted to us in Ptolemy's Almagest; from which it appears that the stars retain at least very *nearly* the same places now as they did at that period. Still the more accurate methods of modern Astronomers, have brought to light minute changes in the places of certain stars, which force upon us the conclusion, *either that our solar system causes an apparent displacement of certain stars, by a motion of its own in space, or that they have themselves a proper motion.* Possibly, indeed, both these causes may operate.

319. If the sun, and of course the earth which accompanies him, is actually in motion, the fact may become manifest from the apparent approach of the stars in the region which he is leaving, and the recession of those which lie in the part of the heavens towards which he is travelling. Were two groves of trees situated on a plain at some distance apart, and we should go from one to the other, the trees before us would gradually appear farther and farther asunder, while those we left behind would appear to approach each other. Some years since, Sir William Herschel supposed he had detected changes of this kind among two sets of stars in opposite points of the heavens, and announced that the solar system was in motion towards a point in the constellation Hercules; but other astronomers have not found the changes in question such as would correspond to this motion, or

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319. If the solar system is really in motion, how may the fact become manifest? Towards what constellation did Sir William Herschel suppose it moving? Has the opinion been confirmed by later observers?

to any motion of the sun; and while it is a matter of general belief that the sun has a motion in space, the fact is not considered as yet entirely proved.

320. In most cases where a proper motion in certain stars has been suspected, its annual amount has been so small, that many years are required to assure us, that the effect is not owing to some other cause than a real progressive motion in the stars themselves; but in a few instances the fact is too obvious to admit of any doubt. Thus the two stars 61 Cygni, which are nearly equal, have remained constantly at the same, or nearly at the same distance of 15″ for at least fifty years past. Meanwhile they have shifted their local situation in the heavens, 4′ 23″ the annual proper motion of each star being 5″.3, by which quantity this system is every year carried along in some unknown path, by a motion which for many centuries must be regarded as uniform and rectillinear. A greater proportion of the double stars than of any other indicate proper motions, especially the binary stars or those which have a revolution around each other. Among stars not double, and no way differing from the rest in any other obvious particular, *Mu Cassiopeiæ* has the greatest proper motion of any yet ascertained, amounting to nearly 4″ annually.

DISTANCES OF THE FIXED STARS.

321. *We cannot ascertain the actual distance of any of the fixed stars, but can certainly determine that the nearest star is more than* (20,000,000,000,) *twenty billions of miles from the earth.*

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320. What length of time is required in order to detect proper motions in the stars? What changes have occurred in the two stars 61 Cygni? What sort of stars indicate proper motions? Of stars not double, what star has the greatest proper motion?

For all the measurements relating to the distances of the sun and planets, the *radius of the earth* furnishes the base line. (Art. 96.) The length of this line being known, and the horizontal parallax of the body, whose distance is sought, we readily obtain the distance by the solution of a right angled triangle. But any star viewed from the opposite sides of the earth, would appear from both stations, to occupy precisely the same situation in the celestial sphere, and of course it would exhibit no horizontal parallax.

But astronomers have endeavored to find a parallax in some of the fixed stars, by taking the *diameter of the earth's orbit* as a base line. Yet even a change of position amounting to 190 millions of miles, proves insufficient to alter the place of a single star, from which it is concluded that the stars have not even any *annual parallax;* that is, the angle subtended by the semi-diameter of the earth's orbit, at the nearest fixed star is insensible. The errors to which instrumental measurements are subject, arising from the defects of the instruments themselves, from refraction, and from various other sources of inaccuracy, are such, that the angular determinations of arcs of the heavens cannot be relied on to less than $1''$. But the change of place in any star when viewed at opposite extremities of the earth's orbit, is less than $1''$, and therefore cannot be appreciated by direct measurement. It follows, that, when viewed from the nearest star, the diameter of the earth's orbit would be insensible.

322. Taking, however, the annual parallax of a fixed star at $1''$, it can be demonstrated that the distance of the nearest fixed star *must exceed* $95000000 \times 200000 = 190000000 \times 100000$, or one hundred thousand times

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321. What do we know respecting the distances of the fixed stars? Have the fixed stars any parallax? What is taken as the base line for measuring the parallax? What angle is greater than would be subtended by the diameter of the earth's orbit as seen from the nearest fixed star?

one hundred and ninety millions of miles. Of a distance so vast we can form no adequate conceptions, and even seek to measure it only by the time that light, (which moves more than 192,000 miles per second, and passes from the sun to the earth in 8m. 13.3sec.,) would take to traverse it, which is found to be more than three and a half years.

If these conclusions are drawn with respect to the largest of the fixed stars, which we suppose to be vastly nearer to us than those of the smallest magnitude, the idea of distance swells upon us when we attempt to estimate the remoteness of the latter. As it is uncertain, however, whether the difference in the apparent magnitudes of the stars is owing to a real difference, or merely to their being at various distances from the eye, more or less uncertainty must attend all efforts to determine the relative distances of the stars; but astronomers generally believe, that the lower orders of stars are vastly more distant from us than the higher. Of some stars it is said, that thousands of years would be required for their light to travel down to us.

323. We have said that the stars have no annual parallax; yet it may be observed that astronomers are not exactly agreed on this point. Dr. Brinkley, a late eminent Irish astronomer, supposed that he had detected an annual parallax in Alpha Lyræ amounting to 1″.13 and in Alpha Aquilæ of 1″.42. These results were controverted by Mr. Pond, of the Royal Observatory of Greenwich; and Mr. Struve of Dorpat, has shown that in a number of cases, the parallax is in a direction opposite to that which would arise from the motion of the earth. Hence it is considered doubtful whether in all cases of

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322. If we take the parallax at 1″, what must the distance be? What time would it take light to traverse this space? How much farther off than this may some of the smaller stars be?

323. Is it entirely settled that the fixed stars have no parallax? What did Dr. Brinkley assert? Have his observations been confirmed?

an apparent parallax, the effect is not wholly due to errors of observation.

324. Indirect methods have been proposed for ascertaining the parallax of the fixed stars by means of observations on the *double stars*. If the two stars composing a double star are at different distances from us, parallax would affect them unequally, and change their relative positions with respect to each other; and since the ordinary sources of error arising from the imperfection of instruments, from precession, and refraction, would be avoided, (since they would affect both objects alike, and therefore would not disturb their relative positions,) measurements taken with the micrometer of changes much less than 1″ may be relied on. Sir John Herschel proposes a method by which changes may be determined which amount to only $\frac{1}{40}$ of a second.*

The immense distance of the fixed stars is inferred also from the fact, that the largest telescopes do not increase their apparent magnitude. They are still points, when viewed with the highest magnifiers, although they sometimes present a spurious disk, which is owing to irradiation.†

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324. What indirect methods have been proposed for ascertaining the parallax of the fixed stars? State the particulars of this method. How minute changes of place is it supposed may be detected. How do the largest telescopes affect their apparent magnitudes?

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* Very recent intelligence informs us, that Prof. Bessel of Königsberg, has obtained decisive evidence of an annual parallax in 61 Cygni, amounting to 0″ .3136. This makes the distance of that star, equal to 657700 times 95 millions of miles—a distance which it would take light 10.3 years to traverse.

† Irradiation is an enlargement of objects beyond their proper bounds, in consequence of the vivid impression of light on the eye. It is supposed to increase the apparent diameters of the sun and moon from three to four seconds, and to create an appearance of a disk in a fixed star, which, when this cause is removed, is seen as a mere point.

NATURE OF THE STARS.

325. *The stars are bodies greater than our earth.* If this were not the case they could not be visible at such an immense distance. Dr. Wollaston, a distinguished English philosopher, attempted to estimate the magnitudes of certain of the fixed stars from the light which they afford. By means of an accurate photometer (an instrument for measuring the relative intensities of light) he compared the light of Sirius with that of the sun. He next inquired how far the sun must be removed from us in order to appear no brighter than Sirius. He found the distance to be 141,400 times its present distance. But Sirius is more than 200,000 times as far off as the sun. Hence he inferred that, upon the lowest computation, Sirius must actually give out twice as much light as the sun; or that, in point of splendor, Sirius must be at least equal to two suns. Indeed, he has rendered it probable that the light of Sirius is equal to fourteen suns.

326. *The fixed stars are suns.* We have already seen that they are large bodies; that they are immensely farther off than the farthest planet; that they shine by their own light; in short, that their appearance is, in all respects, the same as the sun would exhibit if removed to the region of the stars. Hence we infer, that they are bodies of the same kind with the sun.

We are justified therefore by a sound analogy, in concluding that the stars were made for the same end as the sun, namely, as the centers of attraction to other planetary worlds, to which they severally dispense light and heat. Although the starry heavens present, in a clear night, a spectacle of ineffable grandeur and beauty,

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325. *Nature of the stars.* How large are the stars compared with the earth? How did Dr. Wollaston endeavor to estimate the magnitudes of certain fixed stars? How distant would this method make Sirius? To how many suns is Sirius equal?

yet it must be admitted that the chief purpose of the stars could not have been to adorn the night, since by far the greatest part of them are wholly invisible to the naked eye; nor as landmarks to the navigator, for only a very small proportion of them are adapted to this purpose; nor, finally, to influence the earth by their attractions, since their distance renders such an effect entirely insensible. If they are suns, and if they exert no important agencies upon our world, but are bodies evidently adapted to the same purpose as our sun, then it is as rational to suppose that they were made to give light and heat, as that the eye was made for seeing and the ear for hearing. It is obvious to inquire next, to what they dispense these gifts if not to planetary worlds; and why to planetary worlds, if not for the use of percipient beings? We are thus led, almost inevitably, to the idea of a *Plurality of Worlds;* and the conclusion is forced upon us, that the spot which the Creator has assigned to us is but a humble province of his boundless empire.*

CHAPTER IV.

OF THE SYSTEM OF THE WORLD.

327. *The arrangement of all the bodies that compose the material universe, and their relations to each other, constitute the System of the World.*

It is otherwise called the Mechanism of the Heavens; and indeed, in the System of the World, we figure to ourselves a machine, all the parts of which have a mu-

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326. Prove that the fixed stars are suns. For what purpose were they made? Could they have been designed to adorn the night? or as landmarks to the navigator? If they are suns, for what farther purpose were they designed?

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* See this argument, in its full extent, in *Dick's Celestial Scenery.*

tual dependence, and conspire to one great end. "The machines that are first invented (says Adam Smith) to perform any particular movement, are always the most complex; and succeëding artists generally discover that with fewer wheels and with fewer principles of motion than had originally been employed, the same effects may be more easily produced. The first systems, in the same manner, are always the most complex; and a particular connecting chain or principle is generally thought necessary to unite every two seemingly disjointed appearances; but it often happens, that *one great connecting principle* is afterwards found to be sufficient, to bind together all the discordant phenomena that occur in a whole species of things." This remark is strikingly applicable to the origin and progress of systems of astronomy.

328. From the visionary notions which are generally understood to have been entertained on this subject by the ancients, we are apt to imagine that they knew less than they actually did of the truths of astronomy. But Pythagoras, who lived 500 years before the Christian era, was acquainted with many important facts in our science, and entertained many opinions respecting the system of the world which are now held to be true. Among other things well known to Pythagoras were the following:

1. The principal *Constellations.* These had begun to be formed in the earliest ages of the world. Several of them bearing the same names as at present, are mentioned in the writings of Hesiod and Homer; and the "sweet influences of the Pleiades" and the "bands of Orion," are beautifully alluded to in the book of Job.

2. *Eclipses.* Pythagoras knew both the causes of eclipses and how to predict them; not indeed in the ac-

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327. What constitutes the System of the World? Under what image do we figure it to ourselves? What properties characterize the machines first invented?

curate manner now employed, but by means of the Saros. (Art. 168.)

3. Pythagoras had divined the true system of the world, holding that the sun and not the earth, (as was generally held by the ancients, even for many ages after Pythagoras,) is the center around which all the planets revolve, and that the stars are so many suns, each the center of a system like our own. Among lesser things, he knew that the earth is round; that its surface is naturally divided into five Zones; and that the ecliptic is inclined to the equator. He also held that the earth revolves daily on its axis, and yearly around the sun; that the galaxy is an assemblage of small stars; and that it is the same luminary, namely, Venus, that constitutes both the morning and the evening star, whereas, all the ancients before him had supposed that each was a separate planet, and accordingly the morning star was called Lucifer, and the evening star Hesperus. He held also that the planets were inhabited, and even went so far as to calculate the size of some of the animals in the moon. Pythagoras was so great an enthusiast in music, that he not only assigned to it a conspicuous place in his system of education, but even supposed the heavenly bodies themselves to be arranged at distances corresponding to the diatonic scale, and imagined them to pursue their sublime march to notes created by their own harmonious movements, called the "music of the spheres;" but he maintained that this celestial concert, though loud and grand, is not audible to the feeble organs of man, but only to the gods.

329. With few exceptions, however, the opinions of Pythagoras on the System of the World, were founded

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328. What is said of our usual estimate of the knowledge of astronomy possessed by the ancients? What things were known to Pythagoras? How early were the principal constellations known? What did Pythagoras know of eclipses? Also respecting the System of the World? What lesser things did he know? What notions had he of the music of the spheres?

in truth. Yet they were rejected by Aristotle and by most succeeding astronomers down to the time of Copernicus, and in their place was substituted the doctrine of *Crystalline Spheres*, first taught by Eudoxus. According to this system, the heavenly bodies are set like gems in hollow solid orbs, composed of crystal so pellucid that no anterior orb obstructs in the least the view of any of the orbs that lie behind it. The sun and the planets have each its separate orb; but the fixed stars are all set in the same grand orb; and beyond this is another still, the *Primum Mobile*, which revolves daily from east to west, and carries along with it all the other orbs. Above the whole, spreads the *Grand Empyrean*, or third heavens, the abode of perpetual serenity.

To account for the planetary motions, it was supposed that each of the planetary orbs as well as that of the sun, has a motion of its own eastward, while it partakes of the common diurnal motion of the starry sphere. Aristotle taught that these motions are effected by a tutelary genius of each planet, residing in it, and directing its motions, as the mind of man directs his motions.

330. On coming down to the time of Hipparchus, who flourished about 150 years before the Christian era, we meet with astronomers who acquired far more accurate knowledge of the celestial motions. Previous to this period, celestial observations were made chiefly with the naked eye, but Hipparchus was in possession of instruments for measuring angles, and knew how to resolve spherical triangles. He ascertained the length of the year within 6m. of the truth. He discovered the eccentricity of the solar orbit, (although he supposed the sun actually to move uniformly in a circle, but the earth to be placed out of the center,) and the positions of the

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329. Were the opinions of Pythagoras generally embraced by the ancients? What was the doctrine of Crystalline Spheres? How were the planetary motions accounted for?

330. When did Hipparchus flourish? How did he make his observations? What great facts did he ascertain?

sun's apogee and perigee. He formed very accurate estimates of the obliquity of the ecliptic, and of the precession of the equinoxes. He computed the exact period of the synodic revolution of the moon, and the inclination of the lunar orbit; discovered the motion of her node and of her line of apsides; and made the first attempts to ascertain the horizontal parallaxes of the sun and moon.

Such was the state of astronomical knowledge when Ptolemy wrote the Almagest, in which he has transmitted to us an encyclopædia of the astronomy of the ancients.

331. The systems of the world which have been most celebrated are three—the Ptolemaic, the Tychonic, and the Copernican. We shall conclude this part of our work with a concise statement and discussion of each of these systems of the Mechanism of the Heavens.

THE PTOLEMAIC SYSTEM.

332. The doctrines of the Ptolemaic System were not originated by Ptolemy, but being digested by him out of materials furnished by various hands, it has come down to us under the sanction of his name.

According to this system, the earth is the center of the universe, and all the heavenly bodies daily revolve around it from east to west. In order to explain the planetary motions, Ptolemy had recourse to *deferents* and *epicycles*—an explanation devised by Apollonius one of the greatest geometers of antiquity. He conceived that, in the circumference of a circle, having the earth for its center, there moves the center of another circle, in the circumference of which the planet actually revolves. The circle surrounding the earth was called the *deferent*,

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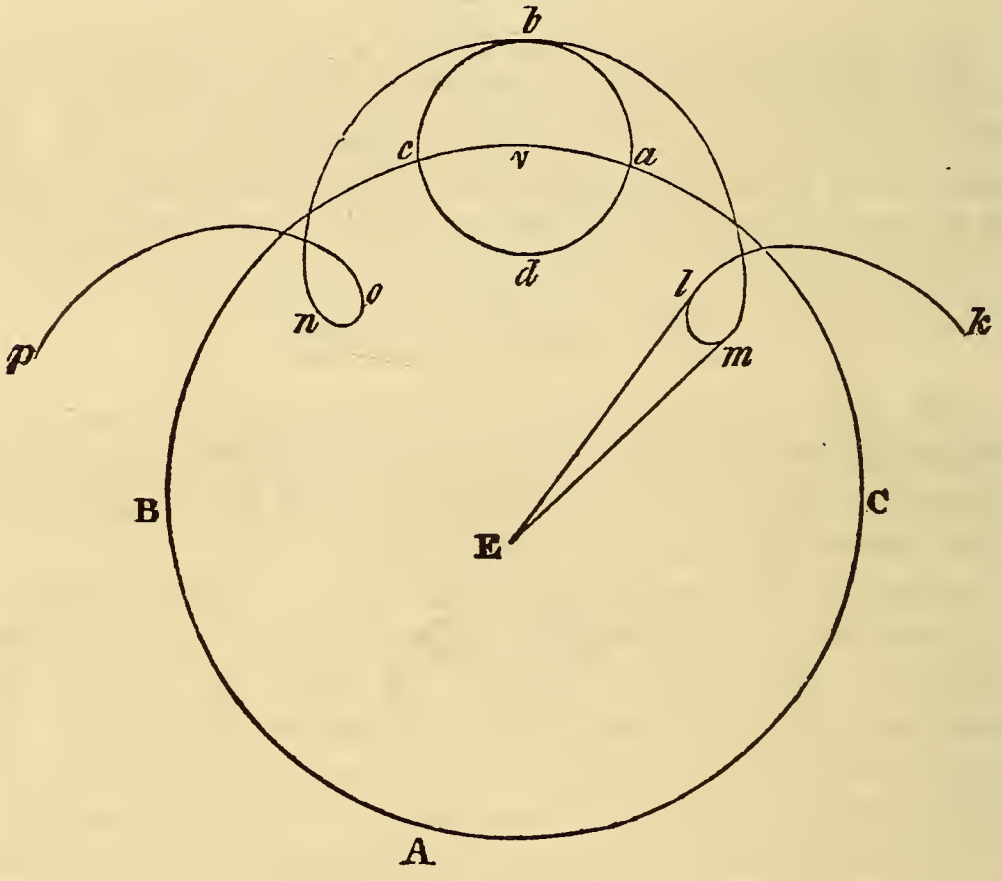
331. What are the most celebrated Systems of the World?

332. *Ptolemaic System.*—Did Ptolemy originate this system? State the outlines of it. What was the deferent? What was the epicycle?

while the smaller circle whose center was always in the periphery of the deferent, was called the *epicycle*. The motion in each was supposed to be uniform. Lastly, it was conceived that the motion of the center of the epicycle in the circumference of the deferent, and of the planet in that of the epicycle, are in the same directions.

333. But these views will be better understood from a diagram. Therefore, let ABC (Fig. 53,) represent the *deferent*, E being the earth a little out of the center.

Fig. 53.



Let *abc* represent the *epicycle*, having its center at *v*, on the periphery of the deferent. Conceive the circumference of the deferent to be carried about the earth every twenty four hours in the order of the letters; and at the

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333. Explain the Ptolemaic System by figure 53.

same time, let the center *v* of the epicycle *abcd*, have a slow motion in the opposite direction, and let a body revolve in this circle in the direction *abcd*. Then a body revolving in the circle *abcd*, and at the same time having a motion eastward in common with the circle, would describe the looped curves *klmnop*. At *l* and *m*, and at *n* and *o*, it would appear stationary, because in these points its motion would be either directly towards or from the spectator. The motion would be direct from *k* to *l*, being in the order of the signs, and retrograde from *l* to *m*; direct again from *m* to *n*, and retrograde from *n* to *o*.

334. Such a deferent and epicycle may be devised for each planet as will fully explain all its ordinary motions; but it is inconsistent with the *phases* of Mercury and Venus, which being between us and the sun on both sides of the epicycle, would present their dark sides towards us in both these positions, whereas at one of the conjunctions they are seen to shine with full face. It is moreover absurd to speak of a geometrical center which has no bodily existence, moving around the earth on the circumference of another circle; and hence some suppose that the ancients merely assumed this hypothesis as affording a convenient geometrical representation of the Phenomena,—a diagram simply, without conceiving the system to have any real existence in nature.

335. The *objections* to the Ptolemaic system, in general, are the following: First, it is a mere hypothesis, having no evidence in its favor, except that it explains the phenomena. This evidence is insufficient of itself, since it frequently happens that each of two hypotheses,

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334. State the objections to this mode of representing the motions of the planets. Why is it inconsistent with the phases of Mercury and Venus? What is said of the supposition of a geometrical center moving around the earth?

directly opposite to each other, will explain all the known phenomena. But the Ptolemaic system does not even do this, as it is inconsistent with the phases of Mercury and Venus, as already observed. Secondly, now that we are acquainted with the distances of the remoter planets, and especially of the fixed stars, the *swiftness of motion* implied in a daily revolution of the starry firmament around the earth, renders such a motion wholly incredible. Thirdly, the *centrifugal force* that would be generated in these bodies, especially in the sun, renders it impossible that they can continue to revolve around the earth as a center.

These reasons are sufficient to show the absurdities of the Ptolemaic System of the World.

THE TYCHONIC SYSTEM.

336. Tycho Brahe, like Ptolemy, placed the earth in the center of the universe, and accounted for the diurnal motions in the same manner as Ptolemy had done, namely, by an actual revolution of the whole host of heaven around the earth every twenty four hours. But he rejected the scheme of deferents and epicycles, and held that the moon revolves about the earth as the center of her motions; that the sun and not the earth, is the center of the planetary motions; and that the sun accompanied by the planets moves around the earth once a year, somewhat in the manner that we now conceive of Jupiter and his satellites as revolving around the sun.

337. The system of Tycho serves to explain all the common phenomena of the planetary motions, but it is encumbered with the same objections as those that have

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335. State the objections to the Ptolemaic System in general. Does it explain all the phenomena? What swiftness of motion does it imply?

336. *Tychonic System.*—State its leading points.

been mentioned as resting against the Ptolemaic system, namely, that it is a mere hypothesis; that it implies an incredible swiftness in the diurnal motions; and that it is inconsistent with the known laws of universal gravitation. But if the heavens do not revolve, the earth must, and this brings us to the system of Copernicus.

THE COPERNICAN SYSTEM.

338. Copernicus was born at Thorn in Prussia in 1473. The system that bears his name was the fruit of forty years of intense study and meditation upon the celestial motions. As already mentioned, (Art. 6,) it maintains (1) That the *apparent* diurnal motions of the heavenly bodies, from east to west is owing to the *real* revolution of the earth on its own axis from west to east; and (2) That the sun is the center around which the earth and planets all revolve from west to east. It rests on the following arguments:

First, *the earth revolves on its own axis.*

1. Because this supposition is vastly more *simple.*

2. It is agreeable to *analogy*, since all the other planets that afford any means of determining the question, are seen to revolve on their axes.

3. The *spheriodal figure* of the earth, is the figure of equilibrium, that results from a revolution on its axis.

4. The *diminished weight* of bodies at the equator, indicates a centrifugal force arising from such a revolution.

5. Bodies let fall from a high eminence, fall *eastward of their base*, indicating that when farther from the center of the earth they were subject to a greater velocity, which in consequence of their inertia, they do not entirely lose in descending to the lower level.

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337. How far does the Tychonic System explain the planetary motions? With what objections is it encumbered?

338. *Copernican System.*—Who was Copernicus? State the principles of his System. State the five reasons why the earth revolves on its axis.

339. Secondly, *the planets, including the earth, revolve about the sun.*

1. The *phases* of Mercury and Venus are precisely such, as would result from their circulating around the sun in orbits within that of the earth; but they are never seen in opposition, as they would be if they circulate around the earth.

2. The superior planets do indeed revolve around the earth; but they also revolve around the sun, as is evident from their phases and from the known dimensions of their orbits; and that the sun and not the earth, is the *center* of their motions, is inferred from the greater symmetry of their motions as referred to the sun than as referred to the earth, and especially from the laws of gravitation which forbid our supposing that bodies so much larger than the earth, as some of these bodies are, can circulate permanently around the earth, the latter remaining all the while at rest.

3. The annual motion of *the earth* itself is indicated also by the most conclusive arguments. For, first, since all the planets with their satellites, and the comets, revolve about the sun, *analogy* leads us to infer the same respecting the earth and its satellites. Secondly, The motions of the satellites, as those of Jupiter and Saturn, indicate that it is a law of the solar system that the smaller bodies revolve about the larger. Thirdly, on the supposition that the earth performs an annual revolution around the sun, it is embraced along with the planets, in Kepler's law, that the squares of the times are as the cubes of the distances; otherwise, it forms an exception, and the only known exception to this law.

340. It only remains to inquire, whether there subsist higher orders of relations between the stars themselves.

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339. State the three reasons why the planets revolve about the sun—how argued from the phases of Mercury and Venus? from the aspects and positions of the superior planets? from the annual motion of the earth?

The revolutions of the *binary stars* afford conclusive evidence of at least subordinate systems of suns, governed by the same laws as those which regulate the motions of the solar system. The *nebulæ* also compose peculiar systems, in which the members are evidently bound together by some common relation.

In these marks of organization,—of stars associated together in clusters,—of sun revolving around sun,—and of nebulæ disposed in regular figures, we recognize different members of some grand system, links in one great chain that binds together all parts of the universe; as we see Jupiter and his satellites combined in one subordinate system, and Saturn and his satellites in another, —each a vast kingdom, and both uniting with a number of other individual parts to compose an empire still more vast.

341. This fact being now established, that the stars are immense bodies like the sun, and that they are subject to the laws of gravitation, we cannot conceive how they can be preserved from falling into final disorder and ruin, unless they move in harmonious concert like the members of the solar system. Otherwise, those that are situated on the confines of creation, being retained by no forces from without, while they are subject to the attraction of all the bodies within, must leave their stations, and move inward with accelerated velocity, and thus all the bodies in the universe would at length fall together in the common center of gravity. The immense distance at which the stars are placed from each other, would indeed delay such a catastrophe; but such must be the ultimate tendency of the material world, un-

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340. Proofs of higher orders of relations among the stars themselves—from the binary stars—from the nebulæ. What do we recognize in these marks of organization?

341. How are these systems preserved from falling into disorder and ruin? How should we be justified in inferring that other worlds are not subject to forces which operate to hasten their decay? To what final conclusions are we led?

less sustained in one harmonious system by nicely adjusted motions. To leave entirely out of view our confidence in the wisdom and preserving goodness of the Creator, and reasoning merely from what we know of the stability of the solar system, we should be justified in inferring, that other worlds are not subject to forces which operate only to hasten their decay, and to involve them in final ruin.

We conclude, therefore, that the material universe is one great system; that the combination of planets with their satellites constitutes the first or lowest order of worlds; that next to these planets are linked to suns; that these are bound to other suns, composing a still higher order in the scale of being; and, finally, that all the different systems of worlds, move around their common center of gravity.

SUPPLEMENT,

CONTAINING AN ACCOUNT OF THE LATEST DISCOVERIES IN ASTRONOMY.

Art. I. GREAT COMET OF 1843.—On the 28th of February, 1843, the attention of numerous observers, in various parts of the world, was arrested by a comet seen at noonday a little eastward of the sun. It resembled a white cloud of great density, being nearly equally brilliant through its whole length, which at this time was estimated by different observers to be about three degrees. During the first week in March, the appearance of the comet in the southern hemisphere was splendid and magnificent, enhanced, in both respects, by the transparency of a tropical sky, and the higher angle of elevation above that at which it was seen by northern observers. At Pernambuco, in South America, on the 4th of March, it presented a golden hue; and it was, as described by the commander of a ship, so brilliant as to throw a strong light on the sea.

At New Haven, the comet was first seen after sunset on the 5th of March, and by the writer on the 6th. It then lay far in the southwest. On account of the presence of the moon, it was not seen under the most favorable circumstances until the evening of the 17th. It then stretched along the southern sky from the point of sunset to the bright star Sirius, covering a space 40 deg. in length, but unusually limited in breadth, the whole figure resembling that of a long goose-quill, being similarly curved. It was, at first, of a delicate rose-red color, but afterwards nearly a pure white.

All the astronomers of the age have concurred in the opinion, that this is one of the most remarkable exhibitions of a comet ever witnessed, although they are not fully agreed respecting the elements of its orbit, or its periodic time. Some maintain that its time of revolution is 175 years, and consequently that the present is its first return since 1668; but others think that its true period is $21\frac{7}{8}$ years, and that it will visit our sphere again in 1865. It passed its perihelion on the 27th of February, at which time it almost grazed the surface of the sun, approaching nearer to that luminary than any comet hitherto observed. Its motions at this time were astonishingly swift, and its brilliancy such as to induce the belief that it was at a white heat through its whole extent.

Art II. Distances of the Stars.—After many fruitless and delusory efforts to measure the immense interval that separates us from the fixed stars, the great Prussian astronomer, Bessel, in the year 1838, determined this interesting and important element by observations on a double star in the Swan, (61 Cygni.)

By observations of the last degree of refinement, conducted for a period of several years, a parallax (see page 36) was decisively indicated amounting to about *one third of a second;* or, more exactly, to 0″.3483, implying a distance of 592,200 times the mean distance of the earth from the sun; or a space which it would take light, moving at the rate of twelve millions of miles per minute, $9\frac{1}{4}$ years to traverse. To form some familiar notions of this distance, let us suppose a railway-car to travel night and day at the rate of twenty miles an hour, we should find it would take it about 547 years to reach the sun; but to reach 61 Cygni would require 324,000,000 of years.

The observations of Bessel enabled him to estimate also the period of revolution of the two stars composing the *Binary System* (see p. 255) of 61 Cygni, and the dimensions of the orbit; and he found the period

about 540 years, and the length of the orbit about $2\frac{1}{2}$ times that of Uranus. Knowing also the distance of this star, we can now determine, from its proper motion (five seconds a year) the *velocity* with which it moves: this is found to be *forty-four miles per second*, —more than double that of the earth in its orbit— amounting to about one thousand millions of miles per annum.

On account of the smallness of the supposed parallax thus found, it would not be unreasonable still to entertain a lingering suspicion, that it is nothing more than the unavoidable imperfection of instrumental measurements; but the most satisfactory evidence which the world can have that such is not the fact in the present instance, but that the parallax is truly found, is that the most celebrated astronomers of the age, after rigorous scrutiny, have acknowledged the reality and soundness of the determination.

Several other stars have of late been supposed to indicate a parallax; and one of them, (*Alpha Centauri*,) the brightest star of the *Centaur*, a constellation of the southern hemisphere, is thought by some to be nearer to us than 61 Cygni, having a parallax of nine-tenths of a second. The evidence, however, upon which this case and several similar cases of supposed parallax rest, is not such as to have inspired so high a degree of confidence as the determination by Bessel, and it is still claimed only that the distance of one star, namely, 61 Cygni, is accurately measured.

Art. III. New Planets.—The discovery of the planet *Neptune* by a distinguished French astronomer, Le Verrier, is one of the most remarkable events in astronomy; both its existence and its place in the heavens having been determined by mathematical calculation, founded on the doctrine of universal gravitation, before it was seen by the telescope. The method of investigation, although laborious and intricate, is not difficult to be understood, and may be explained in

very simple terms. The planet Uranus has long been known to be subject to certain irregularities in its revolution around the sun, not accounted for by all the known causes of perturbation. In some cases, the deviation from the true place, as given by the latter, differs from actual observation two minutes of a degree,—a quantity, indeed, which seems small, but which is still far greater than occurs in the case of the other planets, Jupiter and Saturn for example, and far too great to satisfy the extreme accuracy required by modern astronomy. This long since suggested to astronomers the possibility of one or more additional planets, hitherto undiscovered, which, by their attractions, exerted on Uranus a great disturbing influence.

Le Verrier, assuming the existence of such a planet, applied himself, by the aid of the most profound mathematical calculations guided by the law of gravitation, to the inquiry: *Where* is it situated—at what distance from the sun—and in what point of the starry heavens? As Saturn is nearly twice as far from the sun as Jupiter, and Uranus just twice as far as Saturn, he inferred that, if a planet exists beyond Uranus, its distance is probably twice that of Uranus, or about thirty-six millions of miles from the sun. After reasoning from analogy, and the doctrine of universal gravitation, respecting the position and quantity of matter which a body must have in order to occasion the perturbations of Uranus to be accounted for, and submitting the whole to mathematical calculation, he was enabled to say that the planet was just then passing its opposition, and was consequently most favorably situated for observation, and, on account of the slowness of its motion, would remain in a very favorable position for three months afterwards. Le Verrier wrote to M. Gallé, a practical astronomer of Berlin, communicating his latest results, and requesting him to reconnoitre for the stranger, directing his telescope to a point about five degrees eastward of the well-known star *Delta Capricorni*. That astronomer no

sooner pointed his telescope to the region assigned, than he at once recognised the body, its place being only 52 minutes of a degree distant from the position marked out for it by Le Verrier, and its apparent diameter being almost the same that he had assigned.

By a singular coincidence, a young mathematician of the University of Cambridge, (Eng.,) Mr. Adams, had, without the least knowledge of what M. Le Verrier was doing, arrived at the same great result. But having failed to publish his paper until the world was made acquainted with the facts through the other medium, he has lost much of the honor which the priority of the discovery would have gained for him. Thus two distinguished mathematicians, unknown to each other, and by entirely independent processes, arrived at the same results, as regarded both the existence of the supposed planet, and the region of the starry heavens where at that time it lay concealed; and, to crown all, astronomers, in obedience to the directions of one of them, pointed their telescopes to the spot, and found it there. The conviction on the mind of every one was, that nothing but absolute truth could abide a test so unequivocal.

This is justly regarded as one of the greatest results ever reached by pure mathematical reasoning; and nothing could better convince us of the power of the Calculus, (the highest branch of mathematical science,) as an instrument for guiding human thought in the investigation of truth, than its pointing out the place of a body, which had lain concealed in the starry firmament from the creation of the world to the present time, and which is so small as to be visible only to a large telescope. It is like finding a single pearl buried in the depths of the ocean, or a grain of gold hidden among the sands of the seashore. Nor has any discovery ever more fully illustrated the immutability of truth, and its *fertility*, or that property by which the discovery of one great truth conducts the human mind to others which before lay entirely beyond its reach.

This, as well as many other great truths hidden in the abysses of the universe, is among the legitimate fruits of Newton's grand discovery—the law of Universal Gravitation.

One *satellite* accompanying Neptune has already been discovered, and the existence of another satellite, and of a *ring* resembling that of Saturn, is strongly suspected, but is not fully confirmed.

Asteroids. In addition to the four small planets, Ceres, Pallas, Juno, and Vesta, discovered near the beginning of the present century, and having their orbits in the long space between Mars and Jupiter, five more similar bodies have recently been revealed to us, lying in the same region of the heavens, namely —*Astræa*, *Iris*, *Hebe*, *Flora*, and *Metis*. Like the former, they are very small bodies, as faint stars visible only to the telescope, and are characterized by orbits of greater eccentricity than those of the old planets. This multiplication of asteroids faintly countenances the hypothesis of Dr. Olbers, one of the original discoverers of this class of bodies,—that "they are fragments of a single large planet that once occupied the same region between Mars and Jupiter."

Art. IV. Center of the Universe.—At the end of the preceding work, we have suggested reasons for believing that the whole host of heaven revolve around a common center. Dr. Mædler, of the Imperial Observatory at Dorpat, has recently not only asserted this doctrine, but has endeavored to show the exact position of that center. He fixes it in the *Pleiades*, and asserts that *Alcyone*, the brightest star of this group, is the true "central sun," around which all the stars of our visible firmament revolve, in obedience to the law of universal gravitation. The proofs of this remarkable hypothesis are deemed too incomplete, at present, to command entire assent; but the method of investigation pursued by this distinguished astronomer, opens a new field of observation and of specula-

tion, and promises to lend a new interest to inquirers into the mechanism of the heavens.

Art. V. TELESCOPES.—Practical Astronomy has of late been enriched with a number of great telescopes, which have discovered new wonders in the starry heavens. The most remarkable of these are the grand *Reflector* constructed by Lord Rosse, an Irish nobleman, and the great *Refractors* belonging respectively to the Pulkova, the Cincinnati, and the Cambridge observatories.

Lord Rosse's telescope considerably exceeds in dimensions the great 40 feet reflector of Sir William Herschel, being 50 feet in focal length, and having a diameter of 6 feet; whereas that of the Herschelian telescope was only 4 feet. This unexampled magnitude makes this instrument superior to all others in *light*, and fits it pre-eminently for observations on the most remote and obscure celestial objects, as the faintest nebulæ, for example. But its unwieldy size, and its liability to loss of power by the tarnishing or temporary blurring of the great speculum, will render it far less available for actual research than the great refractors which come in competition with it.

Until recently, it was thought impossible to form achromatic object-glasses for telescopes of more than about five inches diameter; but they have been successively enlarged, until we can no longer set bounds to the dimensions which they may finally assume. The Pulkova telescope (at St. Petersburg) has a clear aperture of about 15 inches and a focal length of 22 feet. That of Cincinnati is somewhat smaller, its object-glass being 12 inches in diameter, and its length 17 feet. The telescope recently acquired by Harvard University, is perhaps the finest refractor hitherto constructed. Its dimensions are nearly the same with those of the Pulkova instrument, but its performances are thought to be superior even to that. It has recently added to the system of Saturn an *eighth satellite.*

These magnificent telescopes have afforded views of celestial objects, more splendid and exciting than any previously enjoyed by man. In a scientific point of view, the most interesting of these revelations consist in the resolution of Nebulæ before deemed irresolvable, and thus countenancing the idea that this term is applicable only to the comparative powers of our instruments; that, if any objects of this class remain unresolved, it will only be because the telescope has not yet acquired the requisite power to separate them into stars. Under these mighty instruments, what was before a faint wisp of fog on the confines of creation, expands suddenly into innumerable suns, composing a glorious firmament of stars. The Cambridge telescope has succeeded in the resolution of the great Nebula of Orion, more complete than had been effected even by Lord Rosse's "Leviathan Reflector," and is thus proved to be one of the finest instruments (probably the finest refractor) in the world.

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